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SUMMARY OF COMMERCIALLY AVAILABLE WATER PURIFICATION SYSTEMS

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Air Force Weapons Laboratory

TECHNICAL REPORT NO. AFWL-TR-71-184

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AIR FORCE WEAPONS LABORATORY

Air Force Systems Command

Kirtland Air Force Base

New Mexico

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This report reviews the capabilities of commercially available water purification systems for possible Air Force application in the Bare-Base Mobility Program. A list of firms which manufacture specific water treatment units and complete water treatment plants is included. The units which they produce are described and their applicability evaluated. The commercially available plants have not been designed with the requirements of the Mobility Program in mind. Many plants have the potential for modification to meet these requirements.

Details of illustrations in this document may be better studied on microfiche

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FOREWORD

This report was prepared by the University of Illinois, Urbana, Illinois, under Contract F29601-70-C-0087. The research was performed under Program Element 63723F, Project 683M, Subtask 3.6.110.

Inclusive dates of research were 28 June 1971 through 22 March 1972. The report was submitted 24 April 1972 by the Air Force Weapons Laboratory Project Officer, Mr. James A. Mahoney (DEE).

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This technical report has been reviewed and is approved.

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ABSTRACT

(Distribution Limitation Statement A)

This report reviews the capabilities of commercially available water purification systems for possible Air Force application in the Bare-Base Mobility Program. A list of firms which manufacture specific water treatment units and complete water treatment plants is included. The units which they produce are described and their applicability evaluated. The commercially available plants have not been designed with the requirements of the Mobility Program in mind. Many plants have the potential for modification to meet these requirements.

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SECTION I

INTRODUCTION

This report discusses existing commercially available water purification systems which are potentially usable by the USAF in the Bare Base Mobility Program. The study was patterned after and is intended to serve as a companion to a study made by James A. Mahoney (Ref. 1), "Summary of Commercial Waste Water Treatment Plants." It was initiated at the request of Brigadier General Archie S. Mayes, USAF DCS Civil Engineering, by letter dated 22 August 1968 (Appendix I).

The USAF is seeking a water treatment and distribution system for use in the Bare Base Mobility Program. The system must be capable of supplying the water needs of a tactical force of 1000 to 6000 men requiring 35 to 100 gallons per day per capita. It must be operable within 72 hours on a world-wide basis and therefore must be easily air transported, assembled and disassembled. The components must be compatible with the C-130 aircraft and the 463L loading system. The system must operate within a temperature range of -25 to 125°F and produce a finished water which will meet the 1962 U. S. Public Health Service drinking water standards irrespective of the raw water quality.

1. PRODUCT QUESTIONNAIRE

This study was initiated with a survey of manufacturers of completely integrated water purification plants and components. A questionnaire, along with covering letter (Appendix II) was sent to a comprehensive list of waterworks equipment manufacturers. The response to the letter was very good, although not all responses were positive since few of the firms contacted manufacture completely integrated water purification plants.

Following the initial mailing, a second mailing of the questionnaire was made as the names of additional potential suppliers became available. The complete list of companies contacted is given in Appendix III. This list in Appendix III is divided into three sections. The first group of companies listed (35) are those which replied positively, indicating that they made or could provide equipment which would meet the stated requirements. The second group (20) replied that they did not supply such equipment and the third group listed (59) did not reply.

2. TREATMENT UNITS AVAILABLE

Of the manufacturers and suppliers who responded, only a portion have complete units available, while others make specific components or can prepare integrated units to specification. A summary of the manufacturers offering water purification units or components is given in Table 1.

TABLE 1

SUPPLIERS OF WATER PURIFICATION UNITS AND COMPONENTS

Supplier	Description of Units
1. Neptune Micro-Floc	"Water Boy"; fully integrated flocculator, tube settler, and mixed media granular filter.
2. Crane Company - Cochrane Division	(a) Microstrainer; filtration for removal of fine solids. (b) Ozonator; oxidation of organic and inorganic reducing agents; sterilization. (c) SVG Automatic sand filter; packaged gravity sand filter with automatic back-wash.
3. Water Treatment Corporation	"Purogen"; mobile water treatment system provides for alum feed prior to pressurized sand filtration followed by ozonation.
4. Northwest Filter Company	"Rotoflow"; fully integrated water treatment system employing mixing, coagulation, settling and gravity sand filtration.
5. Dorr-Oliver, Inc.	"Ultrafiltration"; modular purification system employing semipermeable membranes for solids separation.
6. Westinghouse Electric Corporation, Infilco Division	(a) "Accelapak"; water treatment plant consisting of "Accelator" (solids contact unit and clarifier) plus gravity or pressurized filters. (b) "JBAS"; complete water treatment plant designed for the beverage industry; consists of "Accelator," pressurized filter units in series containing, first, sand, then activated carbon.
Heat Transfer Division	(c) Reverse osmosis unit; highly pressurized membrane separation process for desalting brackish waters.

TABLE 1

Supplier	Description of Units
7. Ionics, Incorporated	"Electric Membrane" process; electrodialysis through semi-permeable membranes to desalt brackish waters.
8. Permutit Company	Package water treatment system providing for chemical feed, solids contact plus settling in the "precipitator," followed by pressurized or gravity filtration. Accessories include units for aeration, degasification, ion exchange, or demineralization by reverse osmosis ("Permasep" hollow fiber permeator).
9. Gulf Environmental Systems	"ROGA" Systems; reverse osmosis system employing spiral wound reverse osmosis modules.
10. Ajax International Corporation	Skid-mounted reverse osmosis units employing "ROGA" modules.
11. Aqua-Chem, Incorporated	Vapor compression distillation plants for desalting of seawater; reverse osmosis units for desalting brackish waters.
12. California Filter Company	Packaged mixed-bed demineralizers for ultrapure water; package water treatment units for coagulation, pressurized filtration and carbon absorption.
13. Cosmodyne Corporation	Ion exchange and reverse osmosis units.
14. Desalination Systems, Incorporated	Reverse osmosis package units.
15. E. I. Dupont De Nemours and Company	Manufactures the "Permasep" permeators and modules.
16. Foremost Water Systems Company	"Watermaker"; a desalting unit which evaporates water using waste heat from a fresh-water cooled engine.

TABLE 1

Supplier	Description of Units
17. Har/Van Corporation	Fully automatic diatomaceous earth filtration system.
18. Hayward Filter Company	Pressure filter units employing a variety of media for removal of specific water contaminants.
19. Continental Products of Texas (Hydro-Chem)	Prepackaged water treatment equipment including filtration, demineralization and reverse osmosis.
20. Hydromation Filter Company	Mobile packaged water treatment plants including chemical treatment, sedimentation, and vacuum or pressurized diatomaceous earth filtration; alternately, an "in-depth" filter with a permanent polymer medium.
21. Illinois Water Treatment Company	Water treatment packages "tailored" from ion exchange, coagulation, filtration, degasification, reverse osmosis units.
22. Lockheed Aircraft International	"Aquanomics" sterilizer; activated carbon and micron-sized filters followed by ultraviolet light treatment for disinfection.
23. Mechanical Equipment Company	Vapor compression, multiple effect flash, submerged tube flash, or multiple stage distillation units.
24. Osmonics, Incorporated	Reverse osmosis units.
25. Universal Desalting Company	Gravity-Flow, multiple effect distillation plants.
26. Universal Water Corporation	Reverse osmosis units.

TABLE 1

Supplier	Description of Units
27. Water Refining Company	Custom-designed water systems; principally ion exchange softeners and demineralizers.
28. Western Filter Company	Coagulation-filtration package plants.

SECTION II

REVIEW OF WATER TREATMENT PROCESSES

The upgrading of the raw water to drinking water quality may involve pretreatment of the water, suspended solids removal, organic removal, inorganic removal, and disinfection. It is the purpose of this section to summarize briefly some of the theory and objectives of the various water treatment processes to lay the framework for a discussion of the package plants which is to follow in Section III, IV, and V.

1. PRETREATMENT

A number of treatment processes can be placed under the heading of pretreatment. A surface water which has a particularly high concentration of suspended solids, i.e., greater than 1,000 mg/l, which are readily settleable, may be treated by a process called plain sedimentation. This process involves the provision of detention time in a quiescent tank or basin for the deposition of settleable solids. Plain sedimentation is only used where stream waters carry exceptionally heavy silt loads. It is a process which can be used to decrease coagulant dosages in certain instances.

Disinfection may also be practiced as a pretreatment process. Highly contaminated surface waters having large populations of bacteria and virus should be treated with disinfecting agents to decrease the numbers of these agents prior to entry to the plant. The advantage of doing this prior to inplant treatment is that increased detention times are available and the probability of producing safe water for drinking purposes is greatly enhanced. Disinfecting agents most commonly are compounds of chlorine. Gaseous chlorine (Cl_2) available as a liquid in steel cylinders, calcium

hyprochlorite ($Ca[OCl]_2$), sodium hyprochlorite (NaOCl), and other chlorine compounds are widely used. Another disinfecting agent which could well be used to advantage is ozone. Ozone is an effective disinfectant, particularly in the absence of colloidal solids, and is known to be a more effective cysticidal and virucidal agent than chlorine. Ozonation has not been widely used in the United States because it does not produce a residual, however.

A pH adjustment step may also be necessary for subsequent treatment. Frequently, solids removal processes involving precipitation and coagulation are pH dependent and necessitate such a step. The pH may be raised by passing the water through a bed of calcite (or calcium carbonate) which dissolves as the water passes through it. Alternately, the addition of lime or sodium hydroxide is used to increase pH. The pH may be lowered by the addition of sulfuric acid or hydrochloric acid.

2. SUSPENDED AND COLLOIDAL SOLIDS REMOVAL

a. Coagulation - Flocculation

The most common way of removing suspended and colloidal solids is to add destabilizing chemicals which interact with the solids to cause the formation of large aggregates which can readily be moved by sedimentation or flocculation. Coagulation involves the addition of chemical, e.g., aluminum sulfate (alum), ferric sulfate, etc., plus possibly a coagulant aid such as a long-chain polyelectrolyte. The coagulating chemical interacts with suspended solids to destroy their stability and make aggregation possible. Contact between destabilized particles may be promoted by mechanical mixing of the tank, i.e., flocculation. The coagulant aid serves as a bridge between destabilized particles to draw these particles together to form an

aggregate. Frequently, coagulant aids can serve to reduce the total cost of coagulant and to improve sludge handling characteristics, such as dewaterability. A choice of coagulant is based upon its effectiveness in a particular water, cost, shipping and handling, plus the characteristics of the sludge that is produced. In general, the ferric salts have a wide pH range over which they are effective and are desirable for this reason. Also, the sludge which results from ferric ion coagulation has better dewaterability than alum sludge.

b. Solids Removal

Once the solids have been coalesced into larger readily settleable solids, the solids can be removed by different procedures. Most commonly, gravity settling is employed in a rectangular or circular sedimentation tank. Tanks may be dewatered intermittently for the removal of sludge or sludge removal devices may be provided to scrape the solids to a sump in the bottom of the tank where they can be withdrawn by pump. A modification of the settling basin involves the use of "tube settlers." These are discussed later in this report with respect to the "Water Boy" water treatment plant. In settling basins employing settlers the flow is introduced into a package of small diameter tubes through which the flow is laminar. Within the tubes the particles settle to the bottom of the tube from whence they can be collected. The advantage of tube settlers is the short detention time enabled by the short distance which the particles must settle before they are effectively removed from the bulk flow. Thus higher surface loading rates can be used allowing for a substantially smaller sedimentation tank. This may have particular significance in the Bare Base Mobility Program because of the need for compact and transportable water treatment systems.

Solids can also be removed in upflow clarifiers. In an upflow clarifier, the flow is introduced at the center of a cylindrical tank. The flow may be deflected downward by a cylindrical baffle, then vertically upward. Particles which settle faster than the vertical velocity of flow are removed. Particles which settle slower are not removed and pass out of the sedimentation unit. In some vertical sedimentation tanks, particles which settle are allowed to accumulate to within several feet of the overflow from the tank. This sludge "blanket" can be used very advantageously. Small uncoagulated particles in the tank influent which otherwise would not be removed have a greater opportunity to come in contact with larger particles contained in this floating bed and thus are "filtered" out of the bulk flow. This added aggregation further increases settling velocity of the larger particles and enables their removal. In this process, the sludge must be periodically drawn off to keep the blanket from becoming too thick and thus prevent the loss of solids over the effluent weir.

An alternative procedure for removing the integrated solids would be to use the process of flotation. In the flotation process, millions of tiny bubbles are introduced at the bottom of a tank containing aggregates. As the bubbles rise, the aggregated solids attach themselves to the bubble and are lifted to the top of the tank. At the top of the tank they can then be skimmed off and disposed of.

c. Filtration

The gravitational means of removing the aggregated solids are not completely efficient. Similarly, flotation does not remove all the solids which are present. The most common procedure for the removal of the residual solids is to use filters consisting of various types of media. In

water treatment the most commonly used media is sand. Sand can be used either in a pressure or a gravity filter. The advantage of the pressure filter over a gravity filter is that backwash walls are not required. A pressure filter can then be more compact. It could also operate to higher head losses across the filter. Loading rates, however, are approximately the same for pressure and gravity filter.

Multi-media filters consist of either anthracite coal and sand or anthracite coal plus sand and garnet. In this application, media of different densities are used to provide more advantageous pore size distribution throughout the filter bed, to allow in-depth usage of the bed for particle removal.

Diatomaceous earth filters have also been used. Indications are that diatomaceous earth filters will provide a better quality effluent if hydraulic loading rate is constant. However, if surges occur in the hydraulic loading rate, the diatomaceous earth filter experiences break-through much more readily than does the multi-media or the sand filters.

d. Ultrafiltration

Membranes can also be used to separate solids from water. The process of ultrafiltration involves a pressurizing of the feedwater to approximately 50 psi. This feedwater is then introduced into a unit which contains a porous membrane. The membrane permits passage of the water dissolved molecules and ions but retains the solid particles. Ultrafiltration differs from reverse osmosis only in that operating pressure is much lower for ultrafiltration, and that membranes capable of removing dissolved substances as well as particles are used in reverse osmosis.

3. ORGANIC REMOVAL

a. Adsorption onto Activated Carbon

Soluble organic compounds can be removed by several different procedures. One of the most common is by adsorption onto activated carbon. This can be done either by passing the water containing the soluble organics through granular carbon beds or by adding powdered activated carbon along with coagulant to the flow of water through the plant. In the latter case, the activated carbon is removed with the other suspended matter in the solids removal step. With granular carbon, the organic molecules are attached by weak bonds to the surface of the carbon. After the carbon has adsorbed all the molecules that it possibly can, it is removed from service and either disposed of or it is regenerated by thermal techniques for reuse. Thermal regeneration is normally not practiced at small installations, but as a matter of course is always practiced at large installations. Carbon is expensive and regeneration reduces costs.

b. Chemical Oxidation

Other means of removing organic compounds is by oxidation with a chemical oxidizing agent. Agents such as ozone, O_3, permanganate, MnO_4^-, or other agents can be used for this process. Ozone, however, is the one agent which holds much potential in this regard. Since most organic compounds are in a reduced form, ozone oxidizes these compounds and converts them in many cases to carbon dioxide and water. In some instances the end product may not be carbon dioxide; further research is needed to determine what end products are produced when certain organic compounds are oxidized. It is frequently necessary to have ozonation followed by a solids removal step since the oxidation of dissolved inorganic substances such as iron or

manganese, can result in the formation of colloidal precipitates which then must be removed. An additional advantage of ozone is that it may destabilize organic colloids and make it easier to remove these substances from solution.

c. Membrane Processes

Membrane processes, in particular reverse osmosis, can be used as a means for removing organic compounds from solution. The cellulose acetate membrane which is frequently employed in reverse osmosis units has the ability to prevent most organic molecules from passing the membrane with the product water. However, it should be noted that certain molecules such as phenol, acetic acid and other short-chain fatty acids, and other related substances can readily pass through the cellulose acetate membrane. Further research is needed to determine how best to remove these compounds from solution if reverse osmosis is used.

d. Ion Exchange

Ion exchange also has potential for removing organic compounds from solution. Since most organic substances which are present in water are acidic in nature, recent research has shown that it is possible to remove many of these organic compounds by ion exchange resins. The particular advantage of ion exchange resins over activated carbon lies in the fact that ion exchange resins can be regenerated by sodium hydroxide rather than by the thermal procedures required for active carbon. It should be noted, however, that the type of organic molecules present is of particular importance. Some organic molecules are not readily removed by sodium hydroxide and therefore cause fouling and a reduction in adsorption capacity of the ion exchange resin. Ion exchange resins for removal of organic

matter would be particularly advantageous if the resins are also used for inorganic removal.

4. INORGANIC REMOVAL

Several procedures are available for removing inorganic substances from solution. The procedures can be generally classified as selective or non-selective. Selective removal includes procedures for removing iron and manganese plus the softening procedures for calcium and magnesium removal. Non-selective procedures consist of reverse osmosis, electrodialysis, and ion exchange in which essentially all of the inorganic species are removed.

a. Iron and Manganese Removal

Iron and manganese removal can be accomplished by oxidation with subsequent removal of the precipitates by filtration. Substances such as permanganate, chlorine, or oxygen may be used to convert ferrous iron (Fe^{++}) and manganese (Mn^{++}) to ferric iron (Fe^{+++}) and manganese (Mn^{++++}). These latter two states are very insoluble and result in precipitates which can be readily removed by filtration.

b. Softening

Softening can be accomplished by precipitation or by ion exchange. In precipitation a base is generally added to cause calcium to precipitate as a carbonate salt and magnesium to precipitate as the hydroxide. Softening is required to reduce many of the nuisances associated with using hard water. Softening can also be accomplished by ion exchange with sodium ion exchange resins. The passage of water containing calcium and magnesium through these resins results in the exchange of sodium for calcium and magnesium and the reduction in hardness of the water. Regeneration of the spent ion exchange

resin is then accomplished by backflushing with a solution of sodium chloride (NaCl).

c. Reverse Osmosis

Reverse osmosis is able to remove organic compounds and inorganic ions. A reaction vessel is generally required in which the feed solution is pressurized on one side on a semipermeable membrane. The applied pressure is generally in the range of 300 to 600 psi. This applied pressure forces the water molecules through the membrane while the inorganic substances are retained on the feed side of the membrane. This process is particularly effective and is ideal in concept. There are operational difficulties associated with it, however. Fouling of the membrane, deterioration of the membrane, and compression of the membrane to decrease product flux are some of the problems. A significant cost factor is due to the short life of the membranes which are very costly.

d. Electrodialysis

Electrodialysis is also a process based upon the use of membranes. In this system electrodes are used to attract ions of charge opposite to the electrodes. For example, the positive electrode attracts negative ions while the negative electrode attracts positive ions. Between the electrodes are many cells which have been created by using membranes which have alternatively cation-impermeable and anion-impermeable characteristics. The alternation of these membranes results in the production of cells in which product and brine water come out of adjacent cells. This process is fairly effective for salt concentrations in the range of 3000 to 5000 mg/l or less. It cannot be relied upon for higher salt concentrations.

e. Ion Exchange

Ion exchange can also be relied upon to remove total dissolved salts. In this case, cation exchange resins are followed by anion exchange resins. The cation exchange resins are in the hydrogen ion form while the anion exchange resins are in the hydroxide ion form. Cations in the bulk flow are removed with the cation exchange resin releasing hydrogen ion to the bulk flow. Anions are removed by the anion exchange resin with hydroxyl (OH^-) ion being released. The hydroxyl and hydrogen ions combine to form water; the ideal net results in the production of pure water with no dissolved solids. In actuality, the quality of product depends upon operating characteristics, extent of regeneration, affinity of ion exchange resins for the various ions and other factors.

5. DISINFECTION

a. Chlorination

As a final treatment, and as a last measure of safety, waters are generally disinfected. Disinfection most frequently is accomplished in the United States by the use of chlorine. Other substances such as ozone are used in other countries and are gaining more usage in the United States. The purpose of disinfection is not only to provide for the destruction of any microorganisms that might have penetrated the other treatment processes, but also to provide a residual disinfecting capacity as the water travels through the main to the point of use. zone is less desirable than chlorine because it does not produce a lasting residual. However, ozone has better virucidal and cysticidal properties than does chlorine and is more desirable from that standpoint. Possibly, the combined use of ozone and chlorine may be desirable.

b. Ozonation

Ozone, O_3, is an allotropic form of oxygen. It is the second most powerful oxidizing agent known, having about twice the oxidizing tendency as chlorine.

In water treatment ozone has many applications. Principally, it can be used to destroy bacteria, viruses, cysts and disease-causing microorganisms. It differs from chlorine in this application in two important respects. First, it sterilizes, rather than merely disinfects, by killing all living organisms present. Secondly, it is reduced completely to nascent oxygen, O_2, within minutes, leaving no residual. It is probably the residual property of chlorine, and not its cost or disinfecting ability that are principally responsible for its wide use as a disinfectant in municipal water supplies in the United States.

For military water supplies, however, the possibility is great that waters will be drawn from regions where a wide range of chlorine-resistant disease organisms may be present. In addition, the possibility of the artificial contamination of water supplies with biological warfare (BW) agents must be considered. With these increased hazards stemming from a lack of control over the raw water source, ozonation for water sterilization seems highly desirable.

In addition to sterilization, the addition of a strong oxidant such as ozone to water should be expected to readily:

(1) Oxidize iron and manganese to ferric and manganese oxides.

(2) Oxidize hydrogen sulfide to elemental sulfur or sulfates.

(3) Oxide organic substances which cause taste, odor or color. (This has been one of the principle uses of ozone to date.)

Of potential importance to the military is the oxidation of organic chemical warfare (CW) agents by ozone. The effectiveness of ozone in this respect is not known. Specific studies of the effect of ozone on nerve gases and other CW agents seem to be in order. If ozone should prove to be effective in inactivating these agents, its use could be highly recommended.

6. SLUDGE HANDLING

Many of the processes which are described above produce sludge in the form of chemical precipitates and other solids. Other residues include brine from the membrane processes, regenerants from ion exchange processes and concentrates from the distillation processes. These residues must be satisfactorily disposed of to avoid polluting the environment. Several different procedures are possible. These include the dewatering of sludge, in some instances, prior to spreading on sand beds for drying; incineration of sludge, perhaps preceded by dewatering; lagooning to receiving waters which have sufficient dilution capacity.

SECTION III

COMPLETELY INTEGRATED WATER PURIFICATION UNITS

The following descriptions and data have been abstracted from the information supplied by the manufacturers that produce completely integrated water purification units.

1. NEPTUNE MICRO-FLOC INC.

The Neptune Micro-Floc Company produces a complete water treatment plant called the "Water Boy." The Water Boy is a completely integrated and packaged water-filtration factory-built unit, which is automatic in operation. It can produce potable water from nearly any surface water, even under adverse conditions where raw water turbidities range up to 2000 units.

The Water Boy provides for chemical feed to the raw water, automatic pH adjustment, flocculation, and settling, filtration through a mixed-media filter bed, and automatic backwash of the filter and settling chamber (Figure 1).

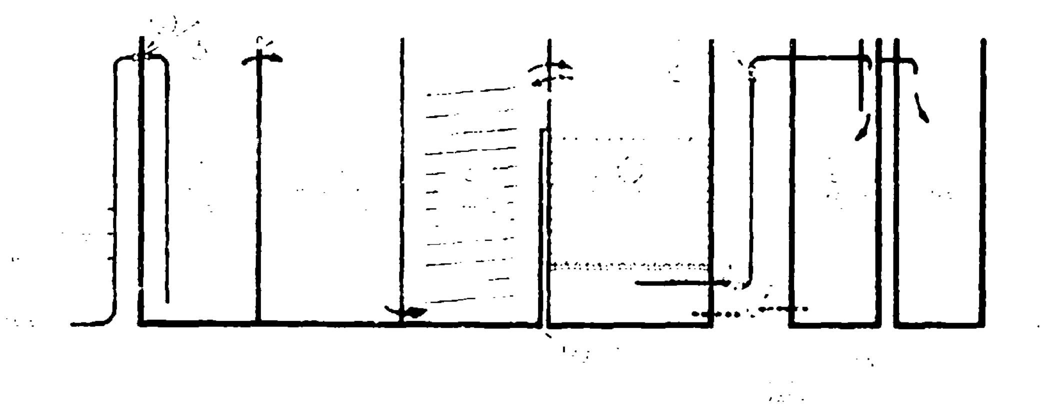


Figure 1. Flow Schematic Diagram for "Water Bc

a. Method of Operation

The method of operation is best explained by reference to Figure 1. Raw water is delivered to the plant by pump or supplied by gravity head. The flow rate through the plant is controlled by a float valve (1) and weir arrangement (2) at the head-end of the plant. A coagulating chemical, most commonly aluminum sulfate, and a chlorine solution for disinfection are added and allowed to mix in the influent piping prior to entering the treatment plant vessel.

The chemically treated water is introduced into a chamber (4) containing granular limestone or calcite through a pipe penetrating the calcite. After the liquid is discharged from the pipe near the bottom of the chamber (4), it flows up through the calcite bed to exit the chamber. The water overflows into the flocculation basin (5) through a rectangular weir opening (2) which serves as a means of measuring the plant flow. In this basin (5), which is partitioned at the mid-depth by a baffle arrangement, mixing and turbulence is imparted by means of an agitator mechanism consisting of a paddle stirrer attached to a vertical shaft.

The flocculated water flows from a point near the bottom of the flocculation basin into a settling basin (6) with a 5 to 10 minute detention. The settling unit is packed with long, narrow, shallow plastic tubes.

Settleable material is deposited on the bottom of the tubes and the clarifier liquid exits from the end of the tubes into a common plenum from which it is allowed to spill over a weir into the filter. The residual particulate matter is separated from the liquid as it passes through a filter media consisting of coal, sand and garnet. This media permits coarse to fine stratification of the media which is maintained after backwashing.

Filtered water collects in a chamber beneath the supporting carborundum plates. The collected water is removed by a centrifugal pump (9) and discharged to a backwash storage tank. To balance the flow rate of the filter with the incoming raw water flow rate, a float-operated throttling valve (10) is placed on the pump discharge.

The backwash sequence is initiated by a predetermined headloss value which is detected by reduced pressure in the filter underdrain chamber. In the cleaning operation, a backwash pump (12) removes filtered water from the backwash storage tank, external to the basic plant, and passes it in a direction reverse to filtration.

Two functions are performed during the backwash procedure. First floc captured in the filter is washed from the bed. Secondly, the sludge captured in the tube settler is flushed out and discharged along with backwash water to waste. Thus, the backwash water does double duty by also providing sludge removal for the plant as well. A siphon which is primed by the rising water level at the start of backwash provides for removal of the waste water.

An optional feature, desirable where unattended operation is required, incorporates a fail-safe turbidimeter to continuously monitor the clarity of the filtered water. This turbidimeter can be integrated into the plant central control system to cause plant shutdown in the event the turbidity of the finished water exceeds a preset limit.

b. Size, Capacity and Cost of Units

The capacity of the Water Boy units ranges from 14,400 to 144,000 gpd, with the largest unit having dimensions of: length-14 ft 5 [illegible], width-6 ft 9 in. and height-6 ft (Table 11). The shipping weight of the lar[illegible] [illegible]nit is 10,000

TABLE II

SIZE, CAPACITY AND COST DATA FOR "WATER BOY" UNITS

Product Description	WB-14	WB-27	WB-82	WB-133
Capacity (gpm)	10	20	60	100
(gpd)	14,400	28,800	86,400	144,000
Weight				
Shipping (lbs)	2,500	3,500	5,000	10,000
Operating (lbs)	5,000	10,000	24,000	42,000
Overall Dimensions				
Length (ft)	6	3.5	8	15
Width (ft)	2.5	3.5	8	7
Height (ft)	4	6	6	6
Foundation Requirements	600 lb/ft^2	600 lb/ft^2	600 lb/ft^2	600 lb/ft^2
Power Requirements	120 V 30 amp 1 phase	120/240 V 30 amp 1 phase	120/208 V 40 amp 3 phase	120/208 V 70 amp 3 phase
Cost[1]	$8,000	$10,000	$16,000	$20,000

1 Cost will vary depending on application and locations. The costs shown include freight and technical assistance during startup for units in the United States and Canada.

pounds while its operating weight is 42,000 pounds. The foundation needed is a base pad that can withstand 600 lb/ft^2. Power supply is e[illegible]ctrical 120/208-V, 3-phase, 70-amp circuit. More detailed data for the la[illegible]st "Water Boy" unit is given in Table III.

On the whole, the "Water Boy" seems to be a well-conceived, simple-to-operate, integrated water purification plant. It uses the most conventional water treatment processes which have been demonstrated to effectively purify both surface and ground water. The size, weight and rated outputs of the

TABLE III

TECHNICAL DATA FOR 100 GPM "WATER BOY"

General Data

Nominal Flow 100 gpm   Maximum Flow 115 gpm

Inlet Pressure Required at Shutoff 15 psig

Effluent Pressure Available at Rated Flow 10 Feet of Water (from base of unit)

Dimensions
Length: 14 ft 5 in.   Width: 6 ft 9 in.   Height: 6 ft 0 in.

Weights:
Shipping weight 10,000 lbs   Operating Weight 42,000 lbs

Equipment Included with Basic Unit

Influent rate set valve - 3 in.

Calcite Column:	39 ft^3 volume,	Calcite Capacity: 3,500 lbs	
Flocculator:	120 ft^3 volume,	Drive: 1/2 HP	RPM: 12
Tube Settler:	150 ft^3 volume,	Overflow Rate: 300 gpd/ft^2	
Filter Area:	20 ft^2,	Media Type: MF-162,	
		Underdrain: Porous Plate	

Pumps: Effluent = 3 HP, 100 gpm
Backwash: = 7-1/2 HP, 400 gpm; flooded suction required

Controls:
Effluent float valve on pump discharge and low filter level float switch included. Control panel provides automatic backwash and return to service initiated by preset filter headloss or by manual initiate pushbutton. Load center and motor starters for pumps also provided.

Finish: Prime Coat

Chemical Feed:

Alum = 102-gal tank, 72-gpd pump - max feed - 120 ppm
Hypochlorite = 55-gal tank, 30-gpd pump - max feed - 10 ppm
Polyelectrolyte = 55-gal tank, 36-gpd pump - max feed - 3 ppm
1/20 HP mixer and disperser included.

Installation Data

Base Pad Design: 600 lbs/ft^2
Electrical Supply (to load center on unit): 120/208-V, 3-phase, 70-amp circuit

Pipe Connections: Inlet - 3 in.
Effluent - 2-1/2 in.
Backwash - 4 in.
Waste - 10 in.

Minimum Backwash Water Storage Required = 4,000 gal   Overhead Clearance = 4 ft

units are on the order of what has been specified for the Air Force application in bare base installation.

2. CRANE COMPANY - COCHRANE DIVISION

a. Microstrainer

Crane/Cochrane produces a microstrainer for the pre-treatment of water containing algae. The unit may be used to improve the performance of existing water treatment facilities.

Microstraining is a simple form of filtration using fabrics woven of very fine stainless steel wire as a filtering medium.

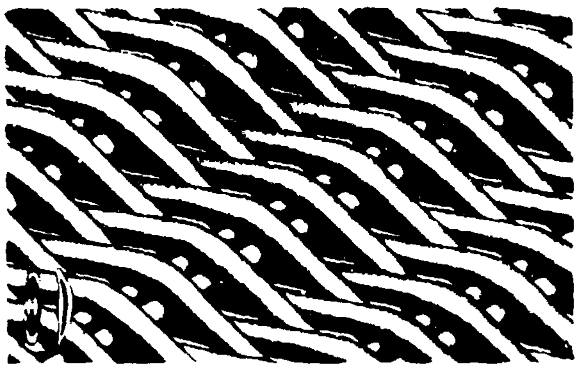


Figure 2 Isometric drawing of Mark I Microfabric with typical diatom (Cymbella) shown against the fabric.

Crane makes three grades of microfabric. Mark 0, the finest, has 144,000 openings per sq in. of surface area (23 micron openings). Mark I, has approximately 80,000 openings per sq in. (35 microns). Finally, Mark II has approximately 58,000 openings per sq in. (60 microns).

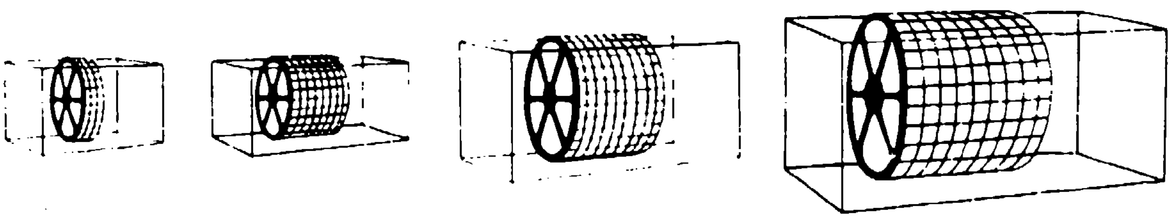
If fabrics this fine were placed in a stream of flowing water containing algae or other finely divided suspended solids, plugging would occur within a minute. To eliminate permanent clogging and provide an unsubmerged area for cleaning, the mesh is mounted on a rotating drum so that it can be backwashed continuously. The passage of fabric through the raw water may only take 20 seconds, but during this short period the fabric

passes from a clean to a fully clogged condition. This is considered a "filter run" of 20 second duration.

The cleaning system consists of two rows of self-cleaning jet nozzles, mounted on a header pipe and installed at the top of the structure spanning the drum length. The nozzles are designed to give powerful stream lines of water with a thin knife-like penetration. These nozzles are designed in an attempt to obtain the highest jet washing efficiency at the lowest possible backwash cost. Splashing from the jets is contained by splash guards with removable inspection panels.

Four standard microstrainer sizes are available. These provide unit flow capacities up to 12 mgd, depending upon the quality of the raw water and the fabric used. For large flows, multiple installations are employed with units arranged for parallel operation.

Packaged units, with the microstrainer drum installed in a steel tank with an integral drive unit and backwash pump are available (Fig. 3).



Drum, Dimensions in feet	5 x1	5 x3	7.5 x5	10 x10
Tank, Dimensions in feet	5.5 x8'x6'	5.8 x9 x14	7 x11 x16	10.2 x14 x22
Motor HP	1/2	3/4	2	5
Capacity mgd	0.06-0.6	0.4-2.0	1.0-5.0	4.0-12.0

Figure 3. Microstrainer Sizes, Capacities and Motor Horsepower.

The water to be clarified enters the drum axially and passes through the filtering medium radially. The water level inside the drum is maintained below the lip of the backwash hopper to eliminate flooding (Fig. 4). Therefore, the top of the drum rotates free and at its highest point passes under the washing jets. The washwater requirement is between 1 and 3% of the volume being filtered.

The total head loss through a microstrainer installation is normally between 12 and 18 inches. The maximum normal head loss across the microfabric itself is only about 6 inches.

The installation costs of microstrainers range from $6,000 to $26,000 per mgd capacity, with the higher unit cost for the smaller units.

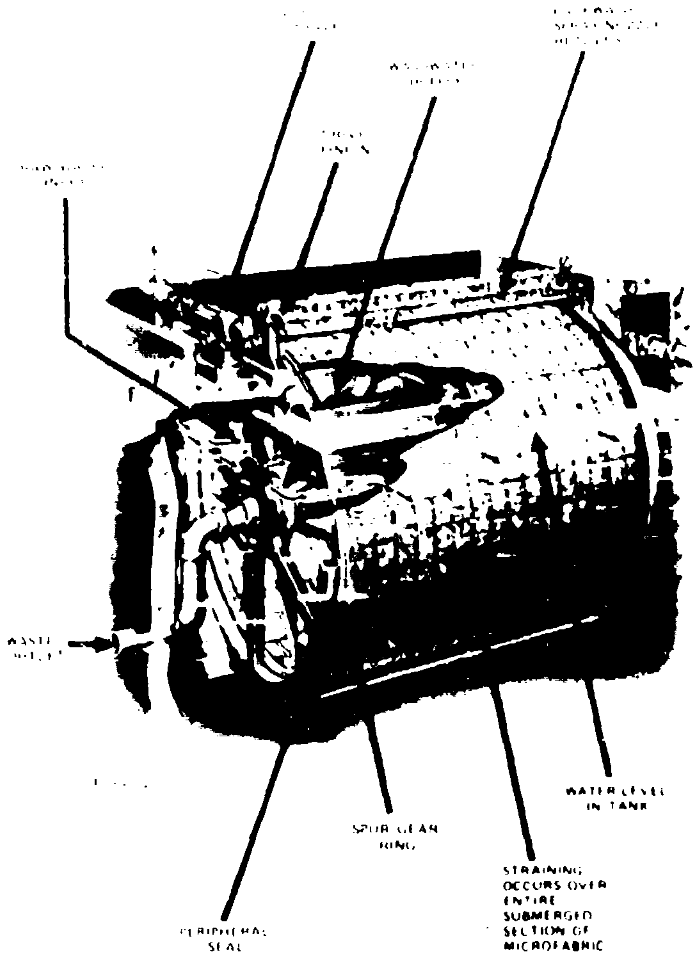


Figure 4.

Microstrainer Installation

b. Micellization - Demicellization Process

The Cochrane Division of Crane Company offers a process for the treatment of surface waters which employs microstraining, ozonation, and filtration. They refer to the process as the "micellization - demicellization" or "M.D." process. This refers to the fact that, following ozonation, some organic substances are rendered insoluble or are destabilized. Therefore, coagulation and filtration are subsequently required.

Ozone dosages for surface waters may be in the range of 1.5 to 3.5 mg/l. Aluminum sulfate dosages required for subsequent coagulation are on the order of the 10 to 30 mg/l required in conventional treatment.

Crane-Cochrane supplies the equipment necessary to produce ozone in a skid-mounted package. The package consists of the following components:

(1) Air compressor with filter, silencer, aftercooler and relief valve. (Atmospheric oxygen is to be converted to ozone.)

(2) Refrigerant-type air drier. (Ozone yield is far higher using dry air.)

(3) Dual-bed, heat reactivated dessicant-type air drier with automatic controls (second stage of drying).

(4) Ozonator with 15,000 volt transformer (electrical discharge type, water-cooled).

(5) Master control panel.

(6) Interconnecting piping and wiring with valves and safety controls.

(7) Rotameter (for air flow regulation).

Figure 5 is a schematic flow diagram for the ozonation unit. Operating costs are estimated on the basis of roughly 8.5 to 9 kilowatt-hours per pound of ozone produced.

Crane-Cochrane supplies horizontal plate-type ozonators (Fig. 6) with from 1 to 25 plates in a single cabinet. Each horizontal plate type ozonator produces 67.2 grams of ozone per hour (3.55 pounds per day). As calculated from Equation 1, this would be sufficient to treat a flow of 100 gpm with a dosage of about 3 mg/l ozone. The daily power consumption would be about 32 kilowatt-hours.

$$\text{Ozone requirements, pounds per day} = \text{Flow, gpm} \times \text{ozone dosage, mg/l} \times 0.012 \qquad (1)$$

The ozone output can be substantially increased by supplying oxygen (100% O_2) rather than air (20% O_2) to the ozonator. In large installations, the capital costs range from $500 to $1,000 for each pound per day of ozone generating capacity.

Finally, Crane-Cochrane supplies a packaged gravity "SVG" automatic sand filter. This pre-designed water plant is available in standard sizes ranging from 50 to 1,000 gpm. While all three components for the "M.D." process are available separately, they have not been integrated into a single package. Presumably this could be done without much difficulty.

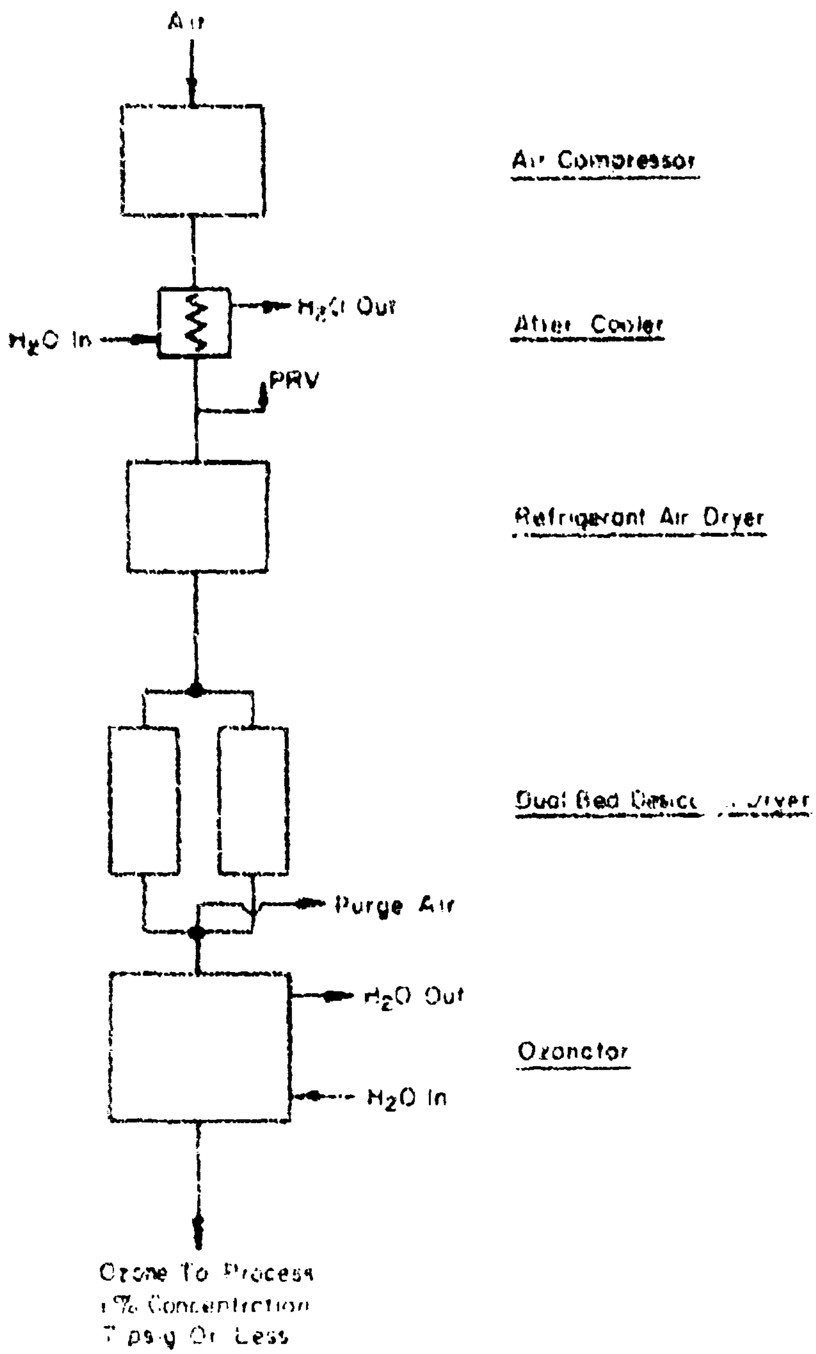


Figure 5 Schematic Flow Diagram Production of Ozone from Air

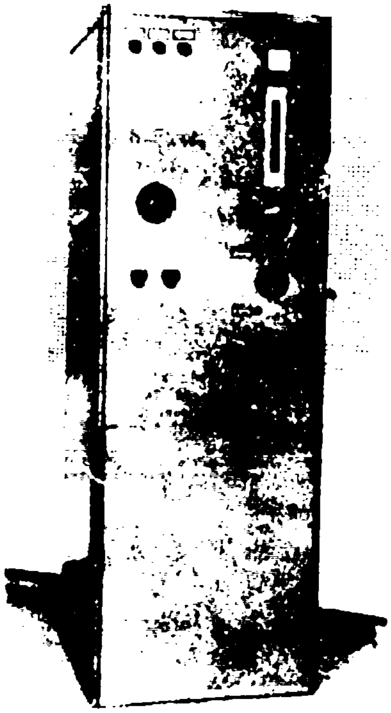


Figure 6. Cabinet Mounted Ozonator
(17-170 g. ozone per hour)

3. WATER TREATMENT CORPORATION

The Water Treatment Corporation has constructed a demonstration mobile water treatment unit employing coagulation and sand filtration followed by ozonation (Fig. 7). The Corporation wishes to sell their demonstration unit, called Purogen M3000, as surplus since they do not intend to pursue this market.

The unit is designed for treating 72,000 gallons daily of surface water. It is 12 feet long, 8 feet wide and 10 feet high and weighs 8,000 pounds. It is equipped with a gasoline driven generator, air compressor and water pumps. The operation is said to be fully automatic and the unit can be put into operation by one man. The flow diagram is given in Figure 8 and the specifications are given in Table IV.

One alteration in design might be appropriate, however. That is, to provide piping and valving for placing the ozonator in line ahead of the coagulation and filtration unit.

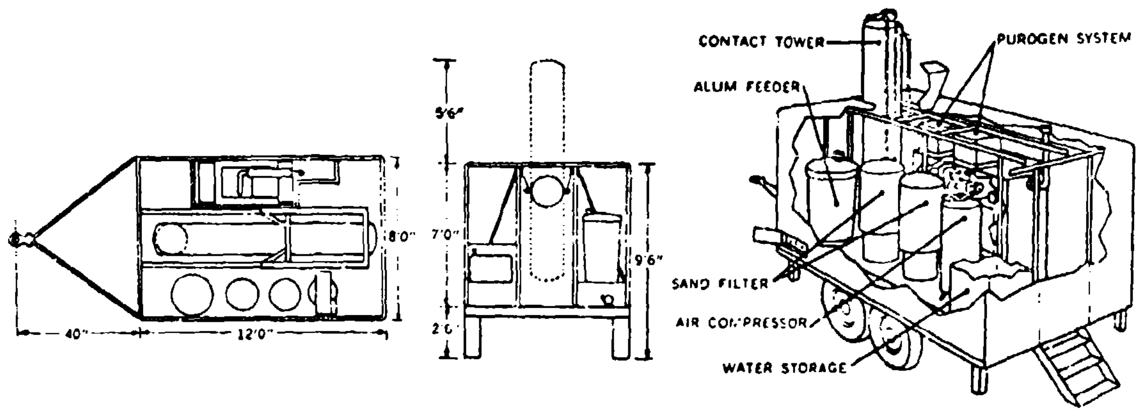


Figure 7. Water Treatment Corporation "Purogen" M3000 Mobile Water Treatment System

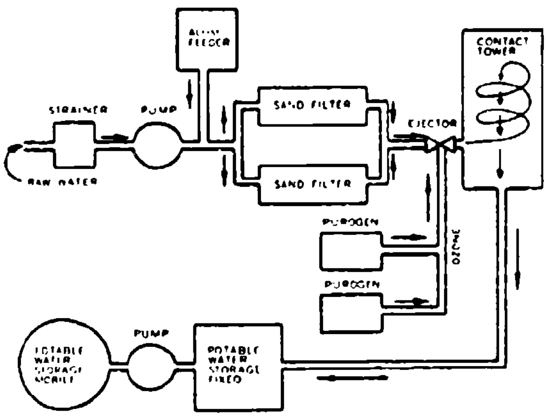


Figure 8. Purogen Mobile Water System Flow Diagram

TABLE IV

SPECIFICATIONS FOR PUROGEN WATER SYSTEM

Equipment	Specifications
Portable Raw Water Pump	50 gpm @ 60 psig, 2 cycle, Gasoline Driven, Single Stage Centrifugal Pump; weight 30 lbs.
Strainer with Strainer Float	
Alum Feed Pump	0-60 gpd; 115 V single phase, 60 cycles.
Superflo Sand Filters	Two, with automatic filtration and backwash; 20 in. O.D. x 30 in.
Plumbing and Piping	Schedule 90 P.V.C. with Quick Disconnect Couplings
Ozone Generators	Two Model 500 Purogen Activated Oxygen Generators, 1 lb/day of Ozone production each.
Ozone Ejector	2 1/2 in. x 2 1/2 in. x 1 1/2 in. P.V.C.
Ozone Contact Tower	Retractable, 10 7/8 in. O.D. x 120 in., 10 ga 304 stainless steel.
Treated Water Storage	Two fiberglass no pressure Tanks, 225 gallons each. One Collapsible Rubber Drum, MIL-D-23119, Tow Bar, 515 gal capacity, weight empty 285 lbs.
Treated Water Pump	50 gpm @ 20 psig, 2 HP, 120/208 V
Motor Generator Set	7 1/2 KVA, Gas Engine Drive
Air Compressor	30 gal, ASME Code, Vertical Tank, 3 HP 208 V, 4.2 C.F.M. @ 80-100 psig.
Control Panel	Contains all Selector Switches, Motor Starters, Status Lamps, Visual Alarm Indicators, etc. for Pumps Purogen Generators & Filters
Flow Rate Indicator	0-100 gpm
Trailer Towing Speeds	50 mph - Hard Surface Roads 30 mph - Gravel Roads
Trailer Parking	30° Maximum Grade & 20° Side Slope without slip or upset; Leveling Jacks at each corner; Retractable Steps at rear.

4. NORTHWEST FILTER COMPANY

The Northwest Filter Company produces a complete water treatment unit called the "Rotoflow." It employs chemical mixing, coagulation, settling, and filtration. It is a completely self-contained unit and can be transported. Installation requires only a firm, level area, water connections and an electrical power source.

Specialized or complicated equipment has been avoided, and no moving equipment which is submerged in water is used. All moving parts have been designed for easy accessibility and maintenance. Fully automatic operation is accomplished by the use of only two control valves. The inlet valve is controlled by the water level and the backwash valve is controlled by the backwash pump pressure.

The plant is manufactured in sizes ranging from 7,200 to 144,000 gpd (5-100 gpm). The dimensions of the 100 gpm plant are 8 x 12 x 24.3 ft long. Dimensions of their other size plants are in Table V.

TABLE V

PHYSICAL DIMENSIONS OF ROTOFLOW WATER TREATMENT SYSTEM

Gallons * Per Hour	Gallons * Per Day (24 hours)	Over-All Tank Dimensions (ft)		
		Height	Width	Length
300	7,200	5	4	7
600	14,400	5	5.5	8.75
900	21,600	5.5	6	11.5
1200	28,800	6	6.5	13.5
1500	36,000	6	7	15.5
1800	43,200	6.5	7.5	15.75
2400	57,600	7	9	17.08
3000	72,000	7	9.5	18.5
3600	86,400	7	10	21
4200	100,800	7	11	22.25
4800	115,200	7	12	23.33
5600	129,600	7.5	12	24.33
6000	144,000	8	12	24.33

*Larger capacity units are available shipped broken down for simple field erection.

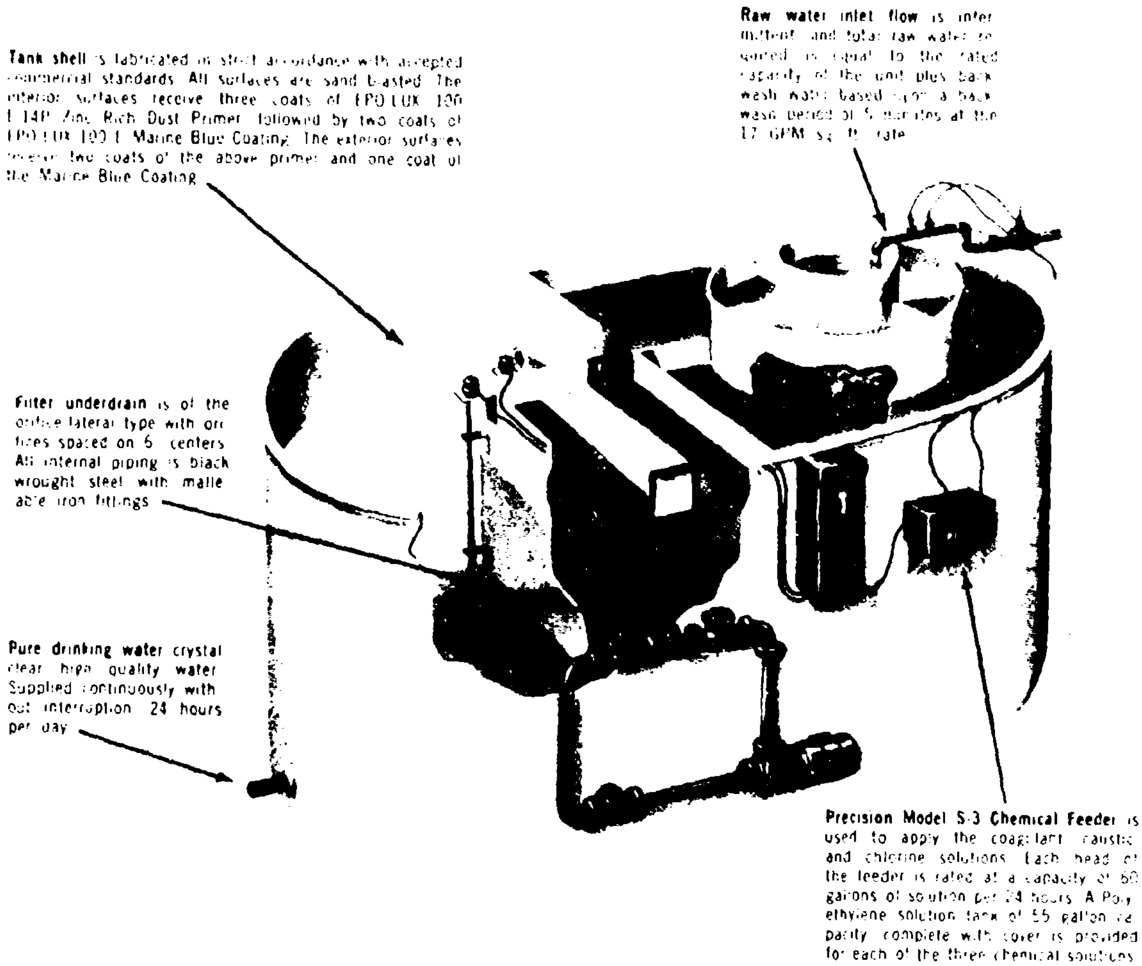


Figure 9. Northwest Filter Company "Rotoflow" Packaged Water Treatment System

The plant provides for the addition of three chemical feeds, (normally an aluminum or iron salt for coagulation, lime for pH adjustment and chlorine for disinfection) to the mixing section of the plant. The mixing and coagulation sections of the plant provide 25 minutes of detention at rated capacity. The sedimentation compartment provides 50 minutes detention before sand filtration.

The filter is designed for 2.2 gpm/sf at rated capacity. Backwash is initiated automatically using a head loss sensing device and is terminated at a predetermined clear well level. The backwash pump will provide water at a rate of at least 17 gpm/sf for 5 minutes. The filter is automatically returned to service after backwash.

The power requirements for the larger "Rotoflow" units, 56 to 140 gpm, are supplied by a 208-220/440- V, 3-phase, 60-cycle electrical circuit.

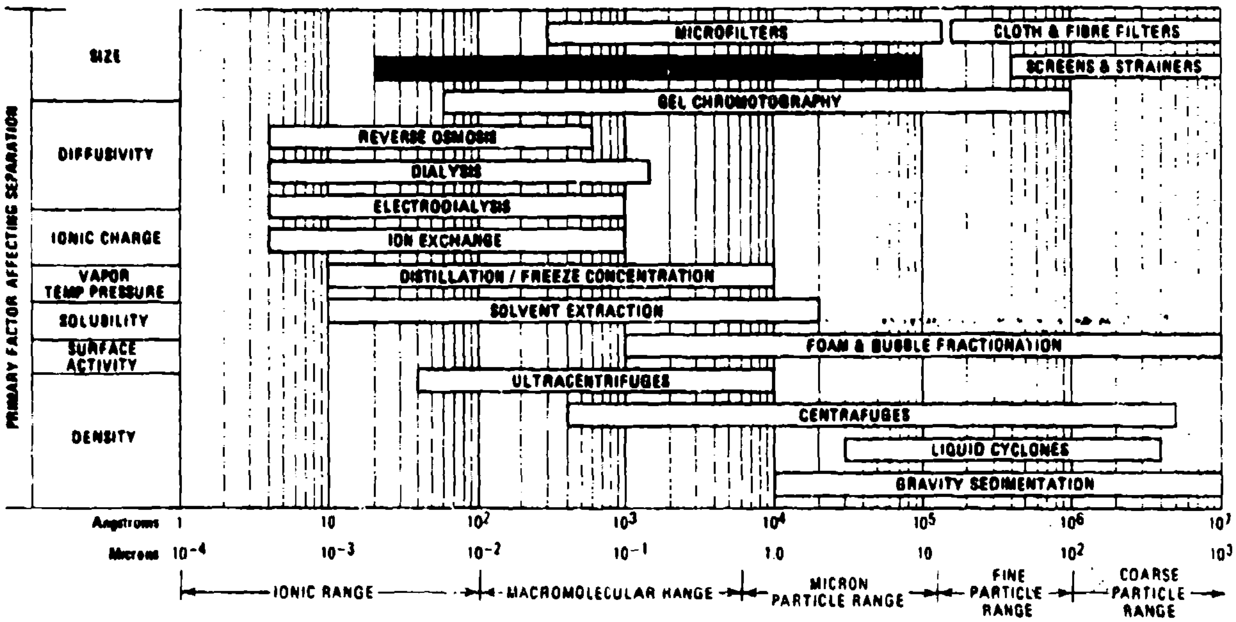
The cost of the units range from about $3,500 for the smallest to $17,500 for the largest.

The process and design parameters employed in the "Rotoflow" are fairly conventional. As a result, assuming proper operation and the absence of any hydraulic upset, the unit should prove highly reliable. The "Rotoflow" units, however, are fairly bulky. The reason for this is that the "Rotoflow" units provide a very substantial amount of clear water storage, allowing for storage of the amount of water required for backwash (up to 3,870 gallons) while maintaining rated output through the backwash period.

5. DORR-OLIVER, INC.

Dorr-Oliver, Inc., manufactures a mobile packaged "Membrane Ultrafiltration Water Treatment System" for the treatment of surface and ground waters. This is a pressure-activated process using semi-permeable membranes which act as screens to separate colloidal materials and some large molecules from the water. Success in the operation of the system is due to the semipermeable membrane, which can discriminate between molecular species on the basis of differences in size, shape, and chemical structure. Above a preselected molecular weight, substances are retained at the membrane surface while the remaining molecules are forced through by hydrostatic

pressure. Figure 10 contrasts the range of particle size separation using ultrafiltration membranes with the ranges for other separation processes.



Useful ranges of various separation processes. *The spectrum of substances to be removed from industrial feedwater and wastestreams range from micromolecules to gross impurities. (Courtesy of Dorr-Oliver).*

Figure 10. Useful Ranges of Various Separation Processes

The Dorr-Oliver ultrafiltration membranes used are non-cellulosic organic polymers having an asymetric, extremely thin (5 microns) surface layer or skin, and a porous substructure of the same material. The total membrane thickness is only 6 to 8 mils; consequently to handle the 20 to 50 psi used in water treatment, the membranes are reinforced with a nonwoven paper material for added mechanical support. Separations take place at the membrane surface and not within the substructure (Fig. 11).

The ultrafiltration systems comprise a series of modules, each providing 60 sq ft of surface area. Each module contains three replaceable

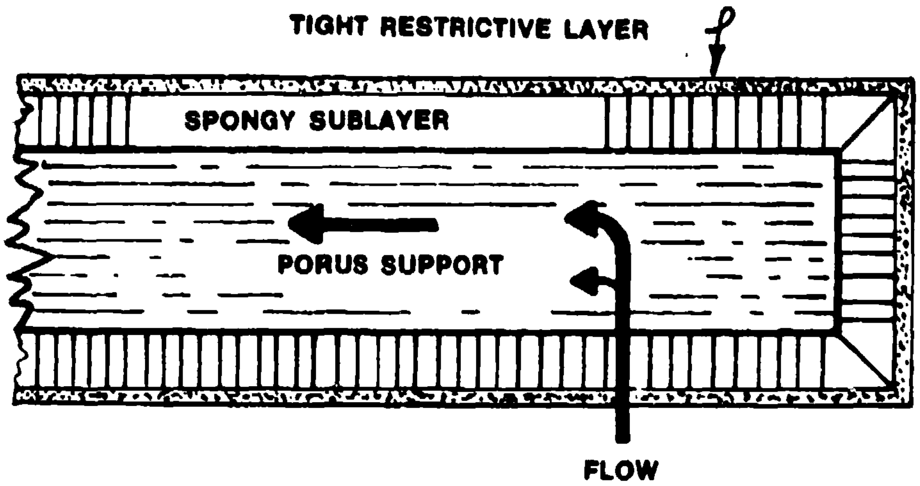


Figure 11. Schematic Membrane and Support Cross Section

cartridges, and each cartridge contains 20 sq ft of membrane housed in a c'ass reinforced polyester casing. The supported membrane sheets are spaced 1/8 inch apart to allow the system to operate under conditions where the feed stream has an appreciable amount of suspended material in it.

Inherent in the use of membranes for phase separation is the fundamental problem of concentration polarization. The separation of one species from another at the surface of a membrane results in local concentration of the rejected species at the membrane surface. This concentration in turn causes an increase in density and viscosity of the laminar sublayer at the surface of the membrane. Associated with these changes is the decrease in membrane flux. The more severe the polarization, the poorer the long term flux characteristics of the membrane.

One technique for minimizing polarization is the establish turbulent mixing in the system to reduce the concentration profile along the flow channel. In Dorr-Oliver systems, this turbulence is obtained by recirculating the feed across the membranes at superficial velocities of 4 to 6 ft/sec (Fig. 12).

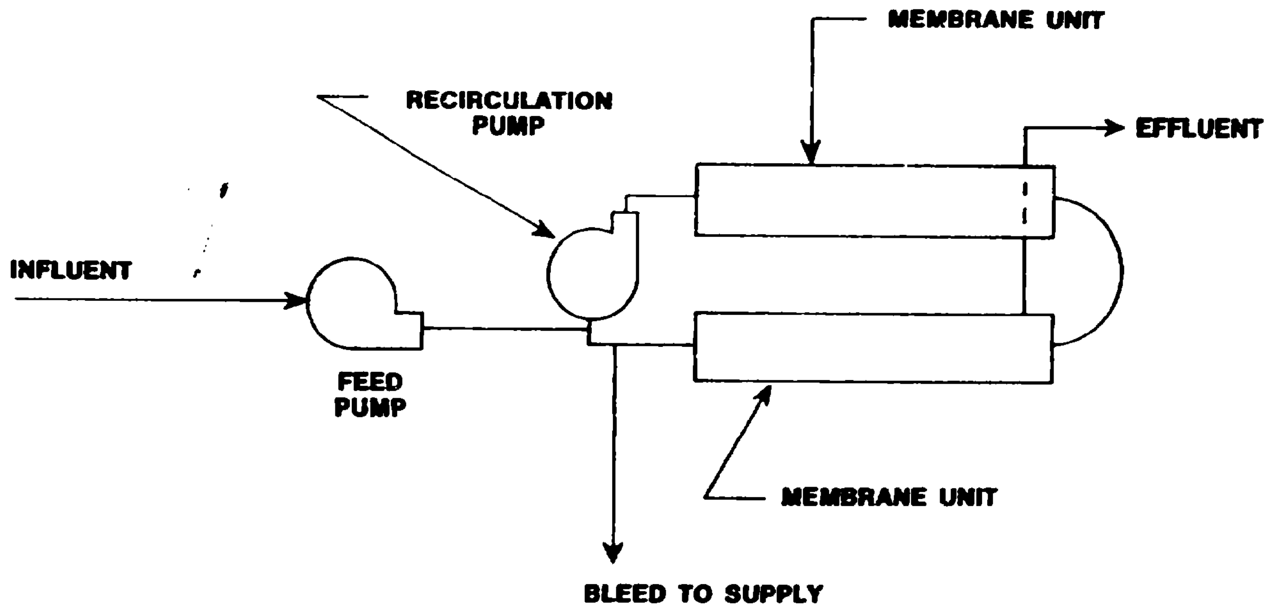


Figure 12

Schematic Diagram of Ultrafiltration Water Treatment System

The hydrodynamic system was designed to facilitate continuous removal of retained substances from the membrane surfaces. A feed-bleed system permits control of retentate concentration.

The cost, weight of plant assembled, and shipping floor area and volume are given in Figures 13 and 14. The dimension of the largest unit is 7 x 22 x 8 ft high. It takes approximately 20 man-days to assemble. The power requirements are normally 60 cycles and units can be placed both in series and parallel to increase capacity. No chemicals are needed.

The Dorr-Oliver "IOPOR" system employs pressures as low as 30 to 50 psi. This is exceptionally low when compared with pressures in the range of 600 to 1500 psi which are normally associated with reverse osmosis. The membranes are selectively structured from a wide variety of organic polymers to provide a spectrum of separations in the range 2,000 to 2,000,000 molecular weight. Assembled from standardized modules (Fig. 15), the system can supply 1,000 to 30,000 gpd. At a flux rate of 25 gallons per sq ft per day, a 60 sq ft module would produce up to 1500 gallons per day.

The design permits easy access to membrane cartridges which must be replaced when the filtrate flux falls off. Membrane life may be on the order of 6 months, more or less, depending on filtration conditions which are not yet well-defined.

Ultrafiltration will result in the removal of suspended and colloidal materials, bacteria, virus, and color-producing organic substances. However, the process will not remove dissolved inorganic materials (salts). No chemicals or other treatment of the water is required.

The total costs of water treatment by ultrafiltration have been estimated by Dorr-Oliver using a flux of 20 gallons per sq ft per day and a

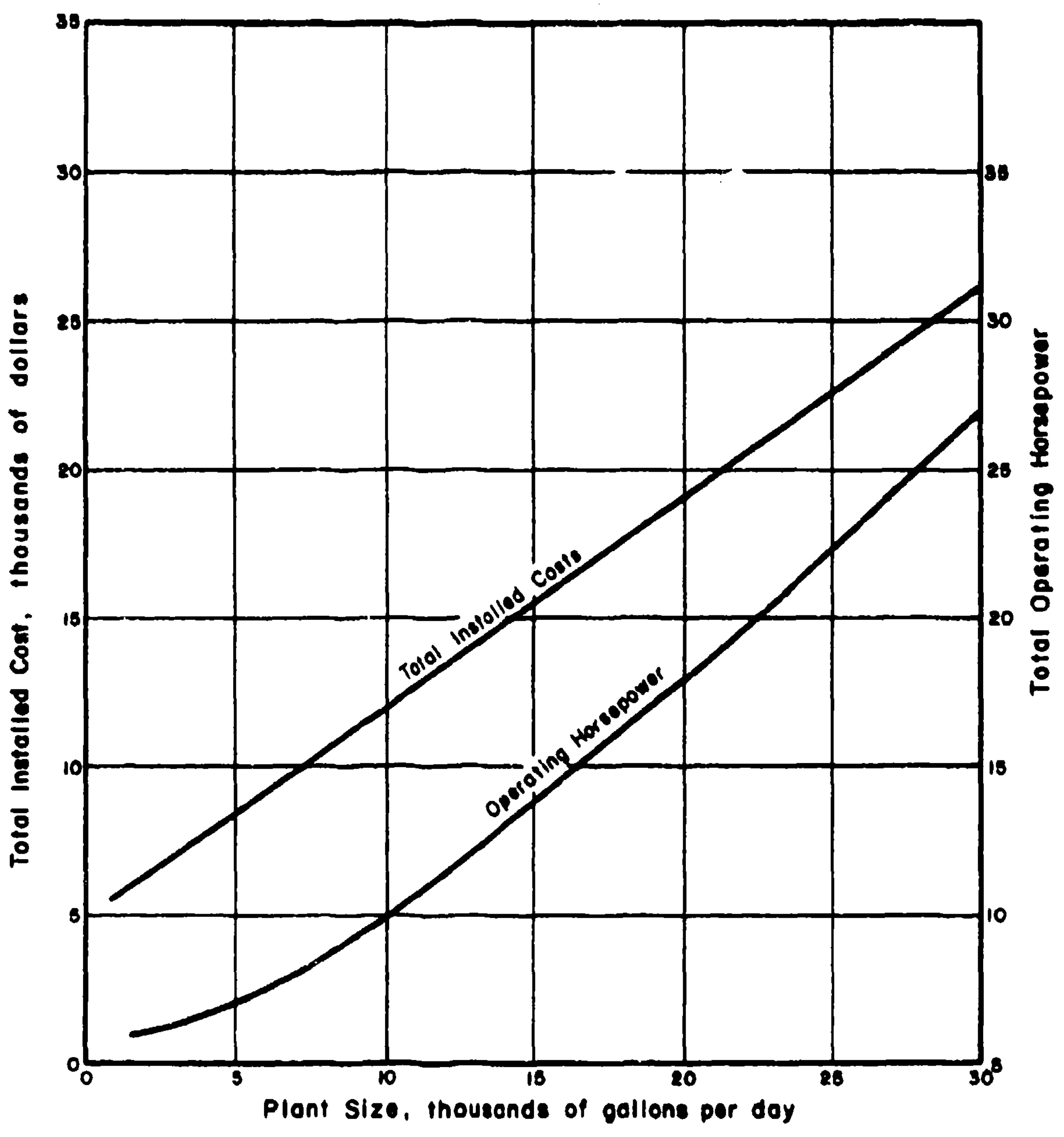


Figure 13. Ultrafiltration Plant Installed Costs

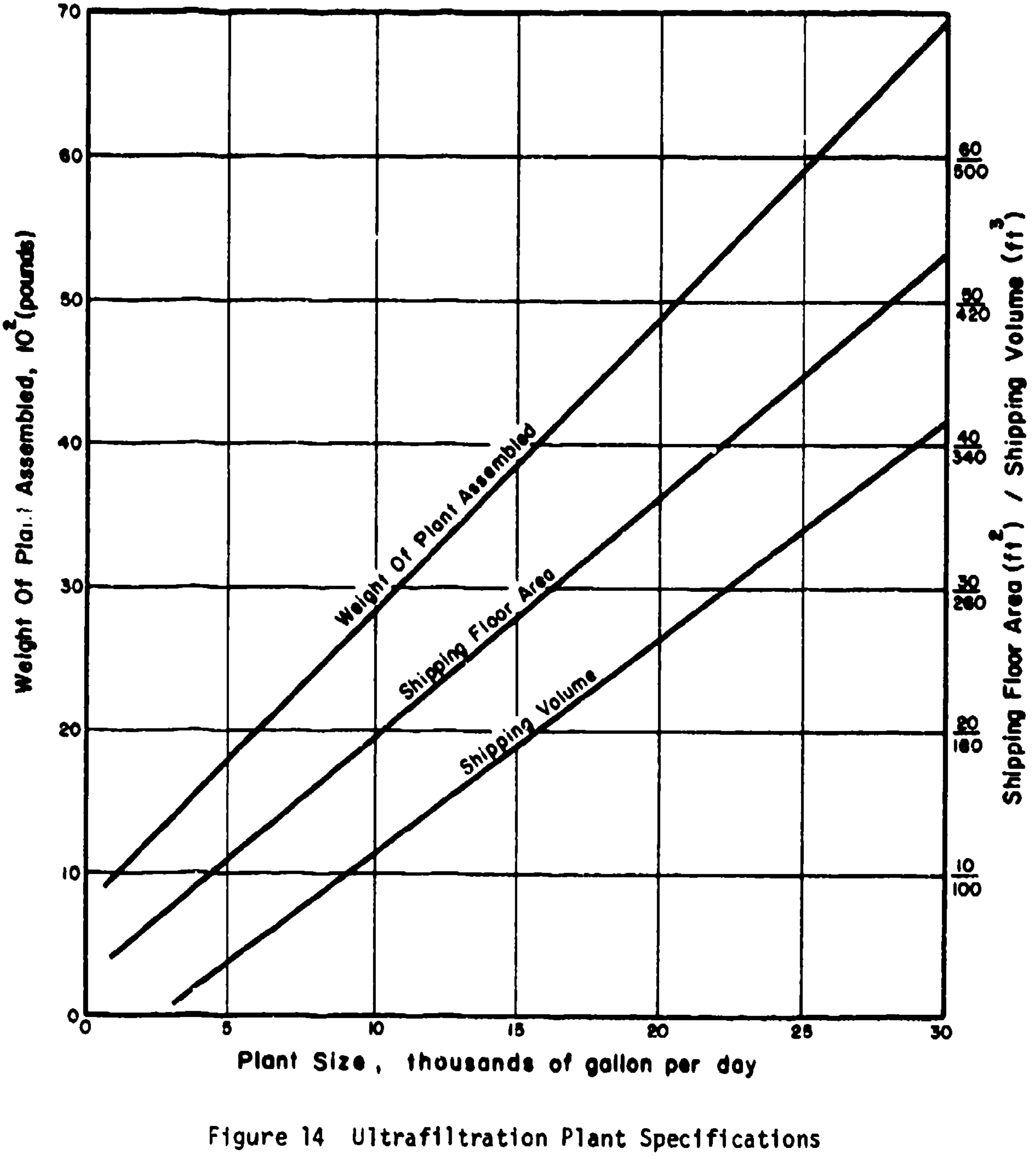
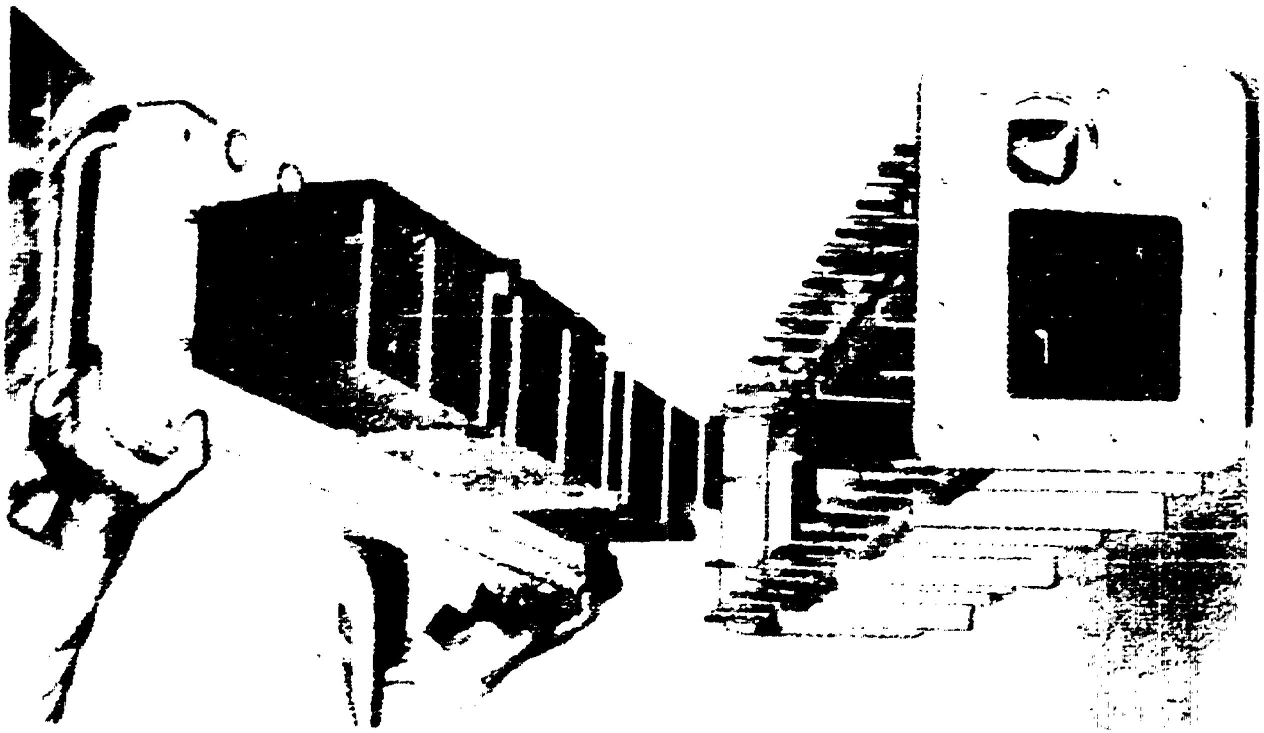


Figure 14 Ultrafiltration Plant Specifications



membrane life of 6 months (Fig. 16). For a 30,000 gpd plant, the total cost would be on the order of $1.00 per 1,000 gallons.

One could safely say that while the ultrafiltration process is very promising, it is still under development. It is conceptually simple, effective in removing organic as well as biological contaminants, and should be "fail-safe." Many of its features would make it attractive for military application. However, its present cost is high, as the manufacturers recognize. They are making intensive efforts to improve membrane technology so as to increase both the flux rate and, more particularly, the life of the membrane.

6. WESTINGHOUSE ELECTRIC CORPORATION - INFILCO DIVISION

a. Accelapak Water Treatment Plant

Infilco produces a complete water treatment plant, which produces potable water softened if required, for domestic or industrial use. The plants have capacities in the range of 40,000 to 500,000 gals/day. They are all of modular design with simple automatic controls and few moving parts to assure dependability with minimum operating attention and maintenance.

The Accelapak Water Treating Plant consists basically of the following components, selected and sized to match the desired flow rate:

(1) Infilco Accelator (solids contact unit and clarifier), Figure 17.

(2) Sand filtration unit.

(a) One, two, or three-bay rectangular gravity filter.

(b) One or two round gravity filters.

(c) Two or three pressurized filters (with surge tank).

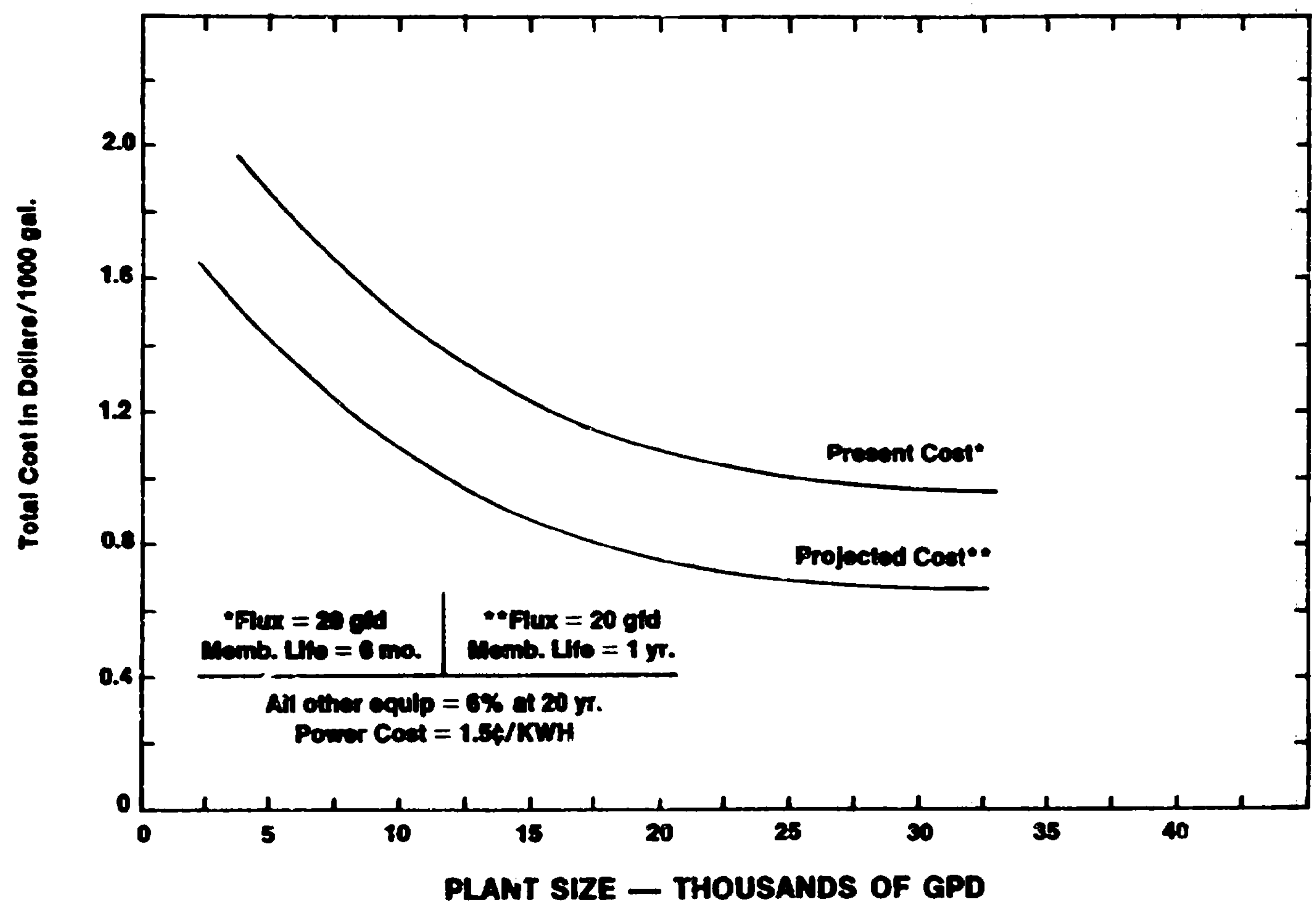


Figure 16

Total Cost for Membrane Water Treatment

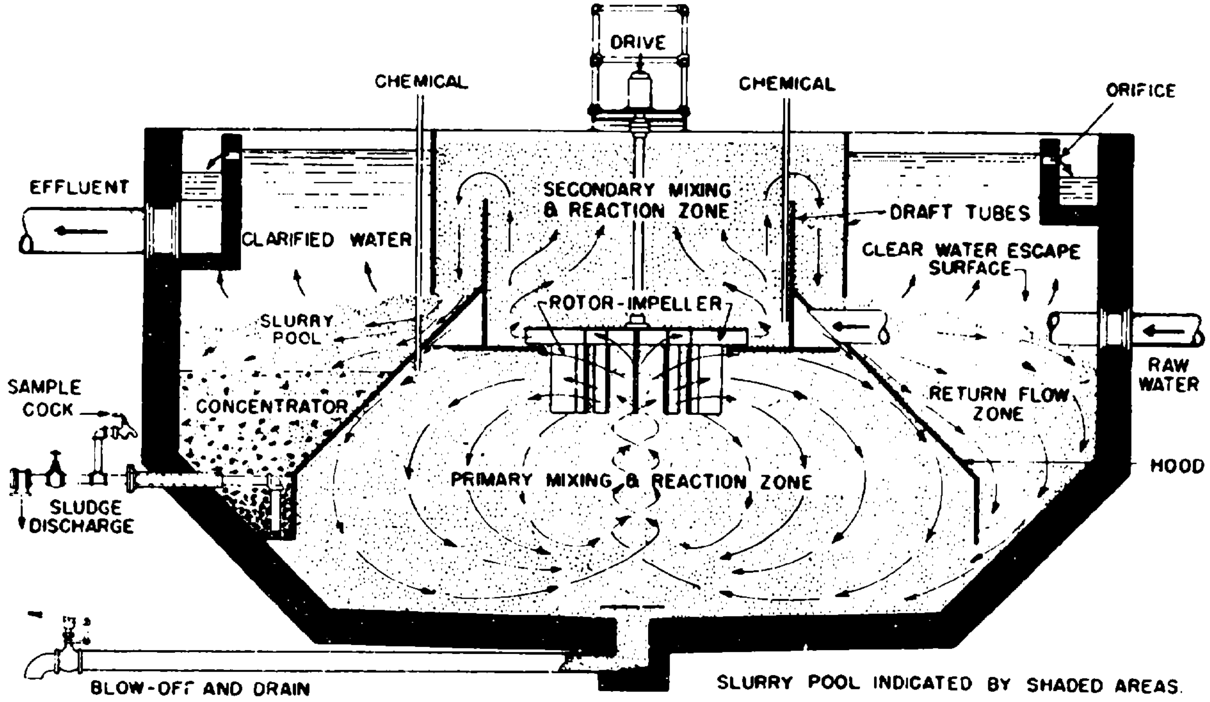


Figure 17. Accelator Unit

(3) Lime slurry feeder.

(4) Solution feeder assembly.

Included as options are such items as:

(1) Pressure filter booster-backwash pump.

(2) Gravity filter backwash pump.

(3) Interconnecting piping to pump.

(4) Effluent control valve for pressure filters.

Where the water is to be softened, hydrated lime or lime and soda ash are used. Corrosion-resistant feeders are furnished for accurate automatic feeding of these alum or iron salts, hypochlorite solution, coagulant aids or limestone. The Accelapak Water Treatment Plant is shown in Figure 18.

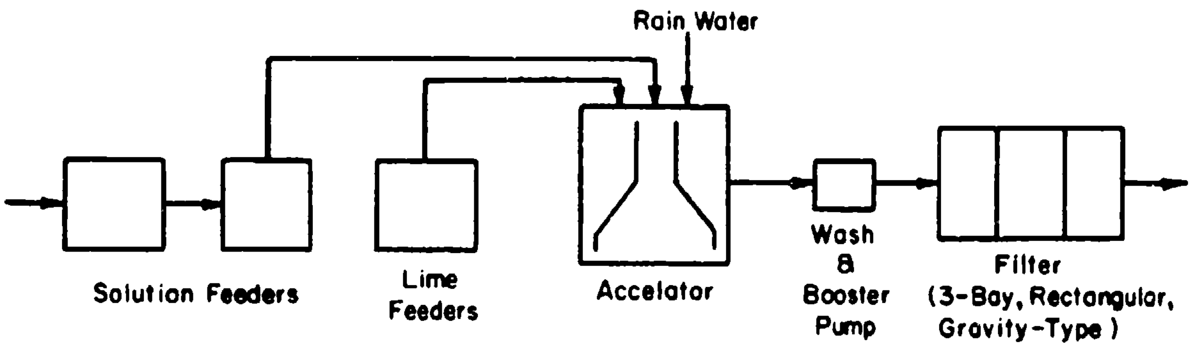


Figure 18. Accelapak Water Treatment Plant

Infilco Accelators are currently being used by the Services. This type of equipment is normally used at a fixed installation such as an air base or headquarters organization. At Osan Air Base, South Korea, a total quantity of 2.25 mgd of treated water is produced utilizing several Accelators in conjunction with rapid sand filters.

One Accelapak unit is designed for 50 gpm (72,000 gallons per day). It costs approximately $20,000 and weighs 25,000 pounds empty. Occupying 160 sq ft of surface area, it consists of two tanks, each 4 ft in diameter by 8 ft high; one tank 8 ft in diameter by 8 ft 6 in. high and several small assemblies consisting of raw water control equipment and chemical feeders. A total of approximately 5 horsepower, 50/60 cycle, are required to operate the plant and roughly 40 man hours are required to assemble it.

b. JBAS Treatment Plant

The Infilco Division also manufactures the "JBAS," a complete packaged water treatment plant, designed for the beverage industry. It employs an Accelator unit plus pressurized filter units, arranged in series. The first filter unit contains sand, and the second, activated carbon. The JBAS is tailored to operate at a constant rate to produce a high quality water. Units are sized to produce roughly 20,000 to 78,000 gallons per day.

The Infilco Division produces a variety of water treatment units with which an effective bare-base water treatment plant could be synthesized.

c. Reverse Osmosis

The Heat Transfer Division of Westinghouse Electric Corporation has developed a 10,000 gpd reverse osmosis unit for desalting brackish water. The unit weighs 6,000 pounds, consumes 7.5 horsepower (440 - V, 3 phase), operates over a pressure range of 300-400 psi and a temperature range of 40-100°F. It has dimensions of roughly 14 ft 6 in. by 6 ft 8 in. and is designed to receive water of up to 5,000 mg/l total dissolved solids. It will reject from 90 to 98% of the dissolved solids, over 99% of bacteria and virus particles and 100% of colloidal material. However, the water may require pre-treatment for pH adjustment before entering the reverse osmosis unit to avoid membrane fouling.

The membrane employed in the Westinghouse System is a tubular membrane supported on a porous resin-bonded sand matrix. It provides a flux of about 16 gpd/sq ft at between 300-450 psi, according to the manufacturer.

7. IONICS, INCORPORATED

Ionics, Incorporated has developed the electrodialysis, or "Electric Membrane" process for the removal of excess dissolved salts and minerals from saline waters. The electrodialysis process is particularly efficient in the treatment of "brackish" waters.

Electrodialysis is a process using electrodes and semipermeable membranes (Fig. 19) that permit the passage of either cations or anions. In electrodialysis, the basic unit is the cell-pair, consisting of a cation and an anion-permeable membrane separated by a spacer for guiding the liquid flow. Many cell-pairs are combined to form a "stack" which includes two electrodes connected to a direct current source. When current is applied across the stack, positive ions move in the direction of the negative electrode (cathode) and the negatively charged ions move towards the anode. As illustrated in Fig. 19, the cation-permeable membrane allows only positive ions to pass through. Similarly, negative ions only pass through the anion-permeable membrane. In every other compartment, one stream is being diluted (product) and in the alternate compartment another stream is concentrated.

One of the notable features on Ionic's electrodialysis equipment is polarity reversing. Controlled by a timer, the electrodes reverse every 15 minutes. The anode becomes the cathode and vice versa. The purpose of this reverse polarity is to prevent scale build-up on the negative electrode (cathode). At the cathode, hydrogen gas is evolved and hydroxyl ions are

left in the solution. At the positive electrode (anode) a reaction takes place resulting in the evolution of chlorine and oxygen gases which will not cause scaling of the elctrode. The waste stream is always routed past the cathode compartment to flush the alkaline solution and prevent scaling.

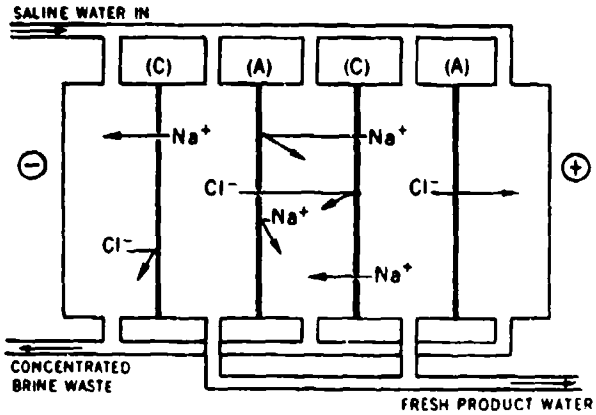


Figure 19. Electrodialysis Process

Other innovations include the use of plastic and non-ferrous materials, especially for piping, to improve reliability; electrodes with a base metal of columbium which are plated with platinum for longer life; the use of automatic controls; and molded spacers in the stack for more efficient operation.

The largest system that Ionics produces is the Aquamite V-2 with a daily capacity of 14,000 to 20,000 gallons. There is a 90-95% removal of minerals from feed water containing up to 6,000 mg/l total dissolved solids. Of the raw water pumped, 80 percent is recovered as potable water.

Shipping weight of the unit is 3,000 pounds. It has dimensions of 11 ft by 3 ft 6 in. by 5 ft high. Electrical requirements are 230/460-V, 3 phase, 20 KVA.

TABLE VI

AQUAMITE SPECIFICATIONS

Specifications	AQUAMITE I*	AQUAMITE III*	AQUAMITE V*	AQUAMITE V-2*
Daily Capacity	500 gal	2000 - 3000 gal	7000 - 12,000 gal	14,000 - 20,000 gal
Percent Mineral Removal	75 - 99%	75 - 99%	75 - 99%	75 - 99%
Maximum Feed Water Mineral Content	450 ppm	6000 ppm	6000 ppm	6000 ppm
Water Recovery	45%	45%	80%	80%
Dimensions (in.)	36x26x54 high	50x36x60 high	108x42x60 high	108x42x60 high
Shipping Weight	500 lbs	1200 lbs	2500 lbs	3000 lbs
Electrical Requirements	110 V, 1Ø, 10 amps	220 V, 1Ø, 20 amps	230/460 V, 3Ø, 22 KVA	230/460 V, 3Ø 22 KVA
Preferred Minimum Feed Pressure	50 psi	50 psi	40 psi	40 psi
Recommended Storage Tank	150-500 gal	2000 - 3000 gal	7000 - 12,000 gal	14,000 - 20,000 gal

* Registered Trademark

8. PERMUTIT COMPANY

a. Package Water Treatment System

Permutit package plants are available in a range from 14,400 (10 gpm) to 144,000 (100 gpm) gallons per day. The systems are reportedly capable of treating any raw water which can meet USPHS minimum standards for use as a potable water source. When the plant is properly operated, it will condition such waters so that the finished effluent consistently surpasses USPHS standards for safe drinking water. For water of higher quality, an aeration, degasification, ion exchange softening or demineralizing step can be appended to the basic plant.

The basic plant provides for chemical feed, solids contact and settling in the "precipitator," and pressurized or gravity filtration. The units are preassembled at the factory. The chemical feeders are plastic-lined tanks that provide for feeding coagulants, alkalis, or hypochlorite solutions (Fig. 20).

The standard equipment on the precipitator includes the agitator drive assembly and motor, flowmeter, float-operated control valve, sampling sink, sample cocks, and test set. Both the agitator and reducer are factory assembled and installed.

The filter can either be pressurized or gravity type with an automatic backwash. Permutit offers an automatic valveless gravity filter, as well as a standard gravity filter.

b. Reverse Osmosis

Permutit also offers a reverse osmosis unit employing the DuPont "Permasep" hollow fiber permeator. Some performance specifications for the module are given in Table VII. The assembly is shown in Figure 21.

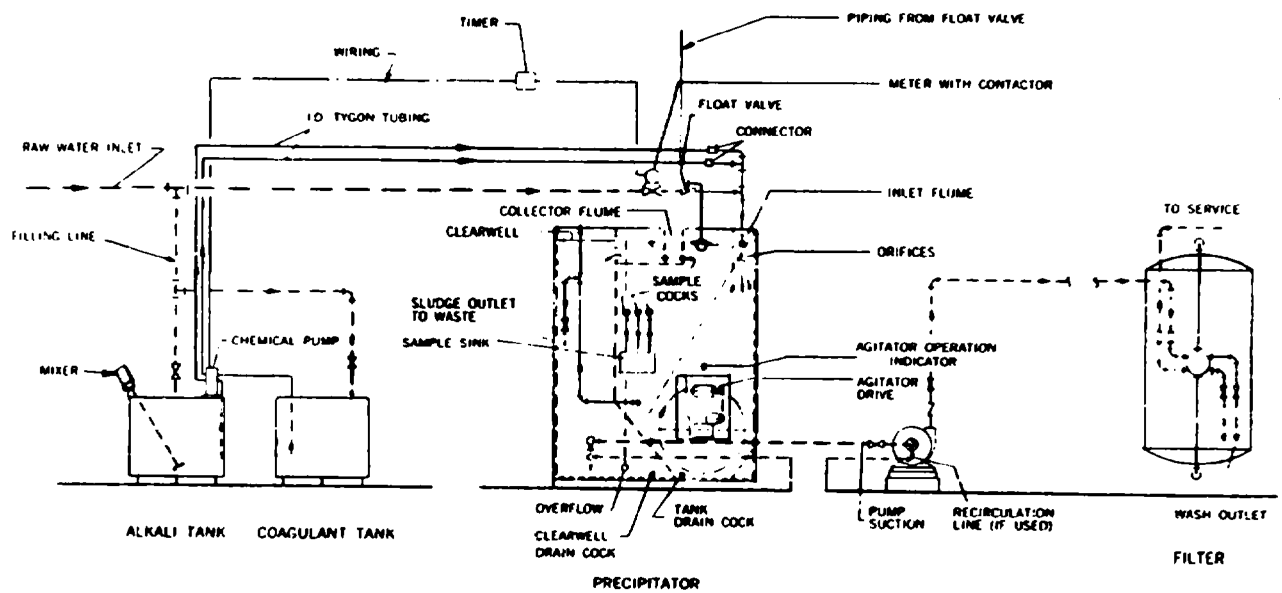


Figure 20. Permutit Package Water Treatment System

TABLE VII

PERMASEP PERMEATER PERFORMANCE

Performance Characteristics	Values
Flux (gallons/day/module)	2000*
Weight	45 lbs, dry - 65 lbs, wet
Diameter (O. D.)	5.5 in.
Shell Construction	4 ft
Organic Removal	Aluminum, 650 psi ASME code
Percent Influent Recovery	Complete+
Salt Rejection	90 - 97%+

* Operating Pressure 400 psi, 68 degrees F

\+ Dependent on water analysis and recovery requirement

9. GULF ENVIRONMENTAL SYSTEMS COMPANY

Gulf Environmental Systems Company is composed of the ROGA Systems Division in San Diego, California and Gulf Degremont in Liberty Corner, New Jersey. ROGA Systems is a manufacturer of reverse osmosis equipment. Gulf Degremont offers other standard water treatment equipment such as high rate filtration units and clarifiers for municipal applications.

Reverse osmosis systems currently manufactured in San Diego range in capacity from a few hundred gallons to several thousand gallons per day.

The following are general capital costs for various sizes of reverse osmosis plants. Each system is composed of a pre-treatment section for conditioning the acidity of the feedwater, a high-pressure pumping assembly to pressurize the conditioned influent to 400 - 700 psi, and a module pressure vessel assembly composed of the required number of pressure vessels to meet system capacity.

TABLE VIII

SIZE, CAPACITY AND COST DATA FOR "ROGA" SYSTEMS

Unit Size (gpd)	Approx. Cost ($)	Approx. Shipping Weight (lb)	Approx. Size, ft
10,000	18,000		
20,000	26,000		
30,000	34,500	3,500	20 x7 x4
50,000	49,000	4,600	20 x10 x 4
100,000	95,000		
250,000	206,000		

10. AJAX INTERNATIONAL CORPORATION

Ajax is a manufacturer of reverse osmosis equipment which is skid-mounted. They note that the feed water usually must be clarified by conventional

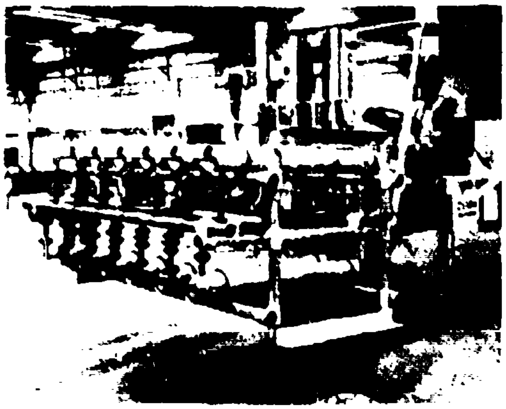


Figure 21. Skid-mounted Permasep Permeator Assembly

clarification processes and the pH must be reduced to between 6.0 and 6.5 prior to application to the reverse osmosis modules. For the latter purpose, the reverse osmosis unit has built-in pumps for feeding chemicals for pH adjustment. Polyphosphates are also added to inhibit scale formation.

Ajax employs the "ROGA" spiral wound reverse osmosis modules manufactured by Gulf Environmental Systems Company. Unit capacities range from 500 to 250,000 gpd. The 100,000 gpd unit weighs 11,800 pounds. Roughly 6-7 KWH are required per 1,000 gpd produced at 75% recovery of feed in the permeate. Sodium hexametaphosphate costs are placed at $0.02/1,000 gallons (Fig. 22).

Membrane life is estimated at 3 years.

11. AQUA-CHEM INCORPORATED

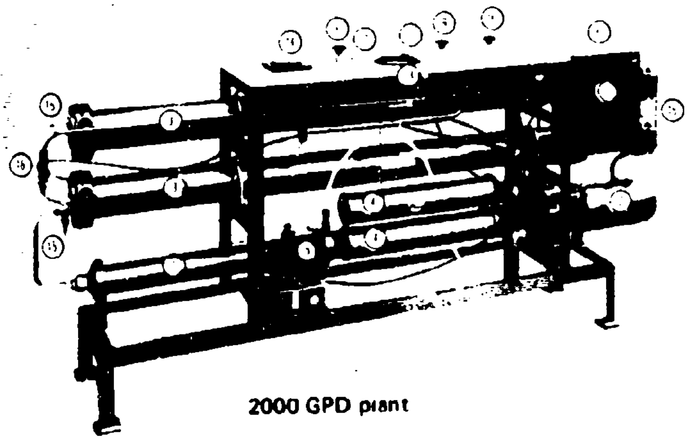
Aqua-Chem manufactures spray-film vapor compression distillation plants with capacities of 4,800, 7,200, and 9,600 gpd. The unit costs are $23,000, $27,000, and $33,000, respectively.

They also manufacture reverse osmosis units of 1,000 to 300,000 gpd capacity. A 14,400 gpd unit costs $42,000.

12. CALIFORNIA FILTER COMPANY (Calfilco)

Calfilco manufactures many water treatment components including solids contactor reactors, horizontal pressure filters, vertical activated carbon filters and package water treatment plants having capacities up to 60 gpm (86,400 gpd). The largest (60 gpm) unit weighs 7,700 pounds. Its filter media weighs 9,600 pounds. It consists of a 5 ft diameter detention tank, a 5 ft diameter pressurized sand filter, and a 45 ft diameter carbon filter unit.

Calfilco also makes fully automated "packaged mixed-bed demineralizers" of up to 60 gpm capacity. The shipping weight is 4,900 pounds.



2000 GPD plant

1. Pump (multistage centrifugal)
2. Pump motor
3. Pressure vessels enclosing reverse osmosis membrane modules
4. Safety prefilters
5. Chemical additive injection pump
6. On/off switches
7. Electrical control box
8. Pressure control valve
9. Recycle control valve
10. Blend (feed ir ... meate) con ... (optional)
11. Feed pressure g... ge before safety filters
12. Feed pressure gauge after safety filters
13. High-pressure gauge before and after modules (two needle gauge)
14. Permeate conductivity (optional)
15. High-pressure line
16. Permeate line

Figure 22. Ajax Reverse Osmosis Plant

13. COSMODYNE CORPORATION

The Cosmodyne Corporation has manufactured an ion exchange unit for the U. S. Army Mobility Equipment Research and Development Center. It was a transportable 72,000 gpd ion exchange unit weighing 7,200 pounds. It had dimensions of 10.7x7.6 ft. The company also manufactures reverse osmosis units up to 100,000 gpd capacity.

14. DESALINATION SYSTEMS, INC.

The company produces a reverse osmosis package unit of 300 and 2,000 gpd capacity. The units cost $1,200 and $3,000,respectively.

15. E. I. DUPONT DE NEMOURS AND COMPANY

In addition to manufacturing the "Permasep" permeators or modules, DuPont had produced a pilot plant weighing 3,350 pounds and producing 7,000-10,000 gallons per day. The unit cost is $13,600. It is 4'6"x3'x6'6". It employs a 220/440V,3-phase, 60-cycle power supply to drive a 10-horse-power motor.

16. FOREMOST WATER SYSTEMS COMPANY

This manufacturer produces the "Watermaker," a desalination unit which utilizes the waste heat from a fresh-water cooled engine as its primary heat source. Each 5 horsepower of engine load rejects sufficient energy to produce 1 gallon of desalted water. The largest evaporation unit is capable of producing about 9,600 gpd. It would require a 2,000 horsepower engine load heat source to be self-sustaining. The weight of the unit is 1,340 pounds and the dimensions are, 3 x 3.5 x 5 ft.

17. HAR/VAN CORPORATION

Har/Van produces a fully automatic diatomaceous earth filtration system. Filter elements are vertical discs housed in a pressure vessel. Automatic sludge removal and drying is an important feature of the unit.

18. HAYWARD FILTER COMPANY

The Hayward Filter Company markets a pressure filter supplied with a variety of media. Different media are used for iron and manganese, chromate, mercury, arsenate, phosphate, and selenium removal.

Flow rates of 20 gpd per sq ft are reportedly possible through the aluminum-bearing granules. It is claimed that the breakthrough of solids is not possible.

19. CONTINENTAL PRODUCTS OF TEXAS (HYDRO CHEM)

Hydro Chem manufactures prepackaged water treatment equipment principally for industrial applications. Units for filtration, demineralization and reverse osmosis are available.

20. HYDROMATION FILTER COMPANY

Hydromation manufactures mobile packaged water treatment plants having capacities from 2,500 to 300,000 gpd. The treatment process includes chemical treatment, sedimentation, filtration and chlorination. A variety of filters are available from Hydromation. These include vacuum and pressurized diatomaceous earth filters, and a unique in-depth filter which uses a permanent polymer medium. The latter has a unique configuration and can be used for the filtration of waters with high solids content, e.g. wastewater.

21. ILLINOIS WATER TREATMENT COMPANY

The Illinois Water Treatment Company produces water treatment plants employing a full range of processes tailored to the requirements of the purchaser. The processes include.

a. Ion exchange

(1) Two-bed systems

(2) Mixed-bed systems

b. Coagulation

   (1) Chemical feed

   (2) Flocculation

c. Filtration

   (1) Sand

   (2) Carbon

   (3) Multi-media

   (4) Sub-micron

d. Chlorination

   (1) Gas

   (2) Liquid - Hypochlorination

e. Removal of radioactive materials

f. Degasification

g. Special processes, such as reverse osmosis.

Specializing in package deionization plants, the company has built a mobile deionizer for the removal of radioactivity from potable water for the U. S. Army, Fort Belvoir, Virginia.

For the Air Force application described, the Illinois Water Treatment Company suggested a plant employing chlorination, coagulation with alum, a dual-media filter, a carbon filter, and rechlorination. Where demineralization is required, they recommend reverse osmosis. Such equipment, they point out, cannot be designed for 300,000 gpd and still stay under a 28,000 pound limitation. The important point that this response illustrates is that this company, and a number of others, are capable of producing water treatment units of almost any configuration providing that definite and reasonable specifications are made. On the whole, this seems to be a very sensible approach to water treatment plant design.

22. LOCKHEED AIRCRAFT INTERNATIONAL LIMITED

Lockheed supplies a portable self-contained water purification unit called the Aquanomics sterilizer. The Model PP300 uses a filtration system consisting of four in-series filters (100 microns; activated carbon; 50 microns; 20 micron filters) followed by an ultraviolet light (2537 Angstroms) sterilizer. The unit produces 6,000 gpd, costs $1,000 and weighs 180 pounds. It is 5'x8'x4' and draws 400 watts from a 50/60 cycle AC generator. Larger units, up to 1,200,000 gpd, are said to be available.

23. MECHANICAL EQUIPMENT COMPANY

Vapor compression, multiple effect flash, submerged tube flash, or multiple-stage flash distillation units are provided by the Mechanical Equipment Company. The capacities range from 120 to 350,000 gpd. Mobile units are diesel driven. A 50,000 gpd unit sells for $116,000 and weighs 39,000 pounds. A scale-preventing chemical must be fed to the sea water feed at the rate of about 0.3 mg/l.

24. OSMONICS, INCORPORATED

Osmonics supplies reverse osmosis units up to 250,000 gpd capacity. Their 50,000 gpd unit costs $50,000, operates at 300 psig and produces a product water at an estimated total cost of $1.74 per 1,000 gallons. At 300 psig, the flux through the reverse osmosis unit is 7 gpd/sf. The membrane life is estimated at 3 years. Salt rejection is 96% for a feed water recovery of 50-80%. There is roughly 100% rejection of organic matter greater than 200 molecular weight (.005 micron).

25. UNIVERSAL DESALTING COMPANY

Universal manufactures packaged gravity-flow multiple-effect distillation plants with capacities ranging from 50,000 to 500,000 gpd. The unit is called the Econostill.

26. UNIVERSAL WATER CORPORATION

Universal Water offers reverse osmosis units producing 1,000 to 18,000 gpd at $1.00 to $3.00 per gallon installed capacity.

27. WATER REFINING COMPANY

Custom design water treatment systems are assembled from mass produced units. Ion exchange softeners and demineralizers are featured.

28. WESTERN FILTER COMPANY

Western supplies coagulation-filtration package plants having capacities from 240 to 720,000 gpd.

SECTION IV

CONFORMANCE WITH CRITERIA

1. RESPONSE OF THE MANUFACTURERS

Some of the manufacturers responding to the questionnaire appeared to lack a complete understanding of the military utilization of water treatment units. Problems of transportability, ease of assembly and disassembly, sludge disposal under temporary field conditions, possibilities of intentional contamination of raw water supplies, operation by continually changing personnel, etc., are not routinely encountered in the waterworks field. As a result, many features which would be desirable from a military standpoint are not designed into packaged water treatment units intended for domestic use.

Partly because of this lack of understanding and, perhaps, partly due to uncertainty about the quality of the raw water influent, many manufacturers did not respond to the questionnaire. Most of them simply submitted descriptive brochures accompanied by brief letters noting their interest and capabilities in water treatment. While data on unit capacities, weights and sizes were provided, except in a few instances, cost data were not. All data are summarized in Tables IX and X.

Manufacturers frequently submitted data as to weights, sizes, and other physical characteristics of individual water treatment components. It appeared that plants could be constructed to adapt to a specified configuration. Therefore, it appears that there are many companies in the United States which produce basic components which can be assembled into package water treatment units meeting the criteria for Bare Base use.

Several manufacturers felt that the objectives as stated were

TABLE IX

SUMMARY OF MANUFACTURER'S DATA ON COMPLETE PACKAGED PLANTS
(Cost, Weight and Size)

Manufacturer	Trade Name and Type of Equipment	Capacity, gpd	Cost, $	Shipping Weight, lbs	Dimensions l x w x h, ft
Neptune Micro-Floc	Water Boy coagulation, filtration	14,400	8000	1800	6 x 25 x 4
		28,800	10,000	3500	3.5 x 3.5 x 6
		86,400	16,000	5000	8 x 8 x 6
		144,000	20,000	10,000	15 x 7 x 6
Northwest Filter	Rotoflow coagulation, filtration	7200	3500		4 x 7 x 5
		14,400	3500		5.5 x 8.8 x 5
		21,600	3500		6 x 11.5 x 5.5
		28,800	3500		6.5 x 13.5 x 6
		36,000	3500		7 x 15.5 x 6
		43,200	3500		7.5 x 15.8 x 6.5
		57,600	3500		9 x 17 x 7
		72,000	3500		9.5 x 18.5 x 7
		86,400	3500		10 x 21 x 7
		100,800	3500		11 x 22 x 7
		115,200	3500		12 x 23.3 x 7
		129,600	3500		12 x 24.3 x 7.5
		144,000	17,500		12 x 24.3 x 8
Dorr-Oliver	IOPOR membrane	1000	(For additional data, see Figure 13 and 14 pages 41 and 42)		
		30,000	26,000	7000	7 x 22 x 8
Westinghouse	Accelapak coagulation, filtration	40,000 72,000 500,000	20,000	25,000	10 x 16 x 8.5

TABLE IX, cont.

Manufacturer	Trade Name and Type of Equipment	Capacity, gpd	Cost, $	Shipping Weight, lbs	Dimensions l x w x h, ft
Westinghouse	JBAS	20,000			
	coagulation, filtration	78,000			
	Reverse osmosis	10,000		6000	14.5 x 6.7
Ionics	Electric	500		500	3 x 2 x 4.5
	Membrane	3000		1200	4 x 3 x 5
	Electrodialysis	12,000		2500	9 x 3.5 x 5
		20,000		3000	9 x 3.5 x 5
Permutit	Precipitator	625			
		6000			
	Permasep Permeator	7000	13,600	3350	4.5 x 3 x 5.7
	reverse osmosis	10,000			
Gulf	ROGA	10,000	18,000		
	reverse osmosis	20,000	26,000		
		25,000	- - -	3500	20 x 7 x 4
		30,000	34,500		
		50,000	49,000	4600	20 x 10.5 x 4
		100,000	95,000		
		250,000	206,000		
Aqua-Chem	distillation	4800	23,000	5100	10 x 4.5 x 6
		7200	27,000	5300	10 x 4.5 x 6
		9600	33,000	7900	10.5 x 5.5 x 6.5
		14,400	42,000	10,700	14 x 5.5 x 6.5
	reverse osmosis	1000	5000		
		300,000			

TABLE [illegible], cont.

Manufacturer	Trade Name and Type of Equipment	Capacity, gpd	Cost, $	Shipping Weight, lbs	Dimensions, l x w x h, ft
Calfilco	coagulation, filtration	10,080			
Foremost	Watermaker distillation	48 - 120		35	0.8 x 1 x 1.3
		120 - 192		60	1 x 1.3 x 1.7
		192 - 394		100	1.2 x 1.5 x 2.2
		394 - 600		150	1.8 x 2.5 x 2.6
		600 - 840		150	1.8 x 2 x 2.6
		840 - 1200		270	2 x 2 x 3.5
		1200 - 1560		270	2 x 2 x 3.5
		1560 - 2400		550	2 x 3 x 4.5
		2400 - 3120		550	2 x 3 x 4.5
		3120 - 4800		960	2.5 x 3 x 5
		4800 - 9600		1340	2.7 x 3.5 x 5
Hydromation	Mobile Packaged Water Treatment Plant, coagulation, filtration	2500			Housed in single trailer
		300,000			
Lockheed Aircraft Corporation	AquaNomics Sterilizer	6000	1000	180	5 x 8 x 4
Mechanical Equipment Company	MECO Distillation	1200	16,830	2100	3.3 x 4 x 5.7
		2640	20,000	3900	5 x 6.5 x 5.7
		4800	26,000		
		7920	28,000	7500	5 x 7.5 x 7
		10,560	32,500	8500	6.5 x 8.5 x 8
		15,840	116,000	39,000	12 x 12 x 12

TABLE IX, cont.

Manufacturer	Trade Name and Type of Equipment	Capacity, gpd	Cost, $	Shipping Weight lbs	Dimensions l x w x h, ft
Osmonics, Inc.	reverse osmosis	250,000	168,000	31,000	Module 8 x 20 x 5 Pump 6 x 4 x 3 Filter 3 x 2 x 5
	reverse osmosis	3000	4350	430	7 x 4 x 1.3
Universal Desalting Corporation	Econostil Distillation	50,000			
Universal Water Corp.	desalination	1000 - 18,000	1-3/gal	600 - 10,000	7 x 6 x 5.5
Water Refining Company, Inc.	demineralizer	720 - 14,400		500	4 x 2 x 5
	demineralizer	720 - 21,600		600	4 x 2 x 5
Western Filter Company	coagulation, filtration	up to 1,800,000			

TABLE [illegible]

SUMMARY OF MANUFACTURER'S DATA ON COMPLETE PACKAGED PLANTS
(Assembly time, Power and Chemical Requirements)

Manufacturer	Trade Name	Capacity gpd	Assembly Time Man-Days (*preassembled)	Power	Chemicals
Neptune Micro-Floc	Water Boy	14,400	*	120 V/30 A	Alum, chlorine, soda ash, poly-electrolyte
		28,800		120/240 V/30 A	
		86,400		120/208 V/30 A	
		144,000		120/208 V/30A	
Northwest Filter	Rotoflow	86,400	*	208/220 V, 3 phase	Alum or iron salts, caustic, chlorine
		100,800		60 cycle	
		115,200		60 cycle	
		129,600		60 cycle	
		144,000		60 cycle	
Dorr Oliver	IOPOR membrane	30,000	20	27 HP	None
Westinghouse	Accelapak	72,000	2	5 HP	Alum or iron salts, hypo-chlorite, lime, limestone
	Reverse Osmosis	10,000		440 V, 7.5 HP	
Ionics	Electric Membrane Electrodialysis	500		110 V/10 A	None
		3000		220 V/ 20 A	
		12,000		230/460 V/22 KVA	
		20,000		230/460 V/22 KVA	

TABLE X, cont.

Manufacturer	Trade Name	Capacity gpd	Assembly Time Man-Days (*preassembled)	Power	Chemicals
Permutit	Permasep Permeator	7000	*	220/440 V, 3 phase 60 cycle, 10 HP	None
Gulf	ROGA				Acid, sodium polyphosphate
Aqua-Chem	distillation	4800	*	460/3/60 or diesel fuel	None
	reverse osmosis	1000	*	115/1/60 to 460/3/60	None
Calfilco	coagulation, filtration	10,080		110 or 220 V	Varies depending on influent
Foremost	Watermaker	48 - 120		.9 KW	
		120 - 192		1.0 KW	
		192 - 394		1.1 KW	
		394 - 600		1.7 KW	
		600 - 840		2.0 KW	
		840 - 1200		2.2 KW	
		1200 - 1560		3.0 KW	
		1560 - 2400		7.5 KW	
		2400 - 3120		7.7 KW	
		3120 - 4800		10.2 KW	
		4800 - 9600		21.5 KW	
Lockheed Aircraft Corporation	AquaNomics	6000	*	50 or 60 cycles	None
Mechanical Equipment Company	MECO		*	No external power required	Nu-Tek (scale preventing)

TABLE X, cont.

Manufacturer	Trade Name	Capacity gpd	Assembly Time Man-Days (*preassembled)	Power	Chemicals
Osmonics, Inc.		250,000	12	100 HP, 60 HP 3Ø, 230/460 V	HCl or H_2SO_4
		3000	*	$60H_2$, 3Ø, 230/460 V	Depends on feed water
Universal Desalting Corporation	Econostil	50,000	*		Acid
Universal Water Corporation		1000 - 18,000	*	50/60 cycle 220 or 440 V	
Water Refining Company, Inc.		720 - 14,400		110 V 60 cycle	HCl, NaOH
Western Filter Company		up to 1,800,000	*		Lime, alum, chlorine

"impossible to achieve." They pointed out that no package could be assembled within the size and weight limitations which would be capable of treating all possible sources of water so as to meet USPHS drinking water standards. In that respect, the units currently used by the military also fall far short of achieving the stated objectives for Bare Base application.

2. REVIEW OF THE CRITERIA

1) Facilities for the USAF Mobility Program must be operable within 72 hours. Most packaged water treatment units appear to require a relatively short time for assembly, on the order of 20 man-days. Modifications to these units could undoubtedly be made to allow for more rapid installation. However, more of the time required for installation of a water supply system may be for the laying of the distribution system.

2) Facilities suitable to support a force of 1,000 to 6,000 personnel will be deployed. It is assumed that a water supply requirement of 35 to 100 gallons/man/day is to be satisfied.

If it is further assumed that all of this water is to be treated to meet USPHS drinking water standards, regardless of water source, the problem of water treatment is greatly magnified. A sufficient number of units must be provided to supply a total of 600,000 gallons per day. These units would have to be capable of treating raw water ranging from sewage to seawater.

The capital costs of providing small-scale units capable of this full spectrum of treatment capabilities would be very substantial. Operating costs, in terms of fuel consumption and maintenance would also be very great.

Alternately, one could set up a schedule of water criteria for various uses at a Bare Base and provide treatment with units sized and selected for that particular use. This is similar to current military practice, where raw water is supplied for some uses whereas filtered and disinfected water are used for others. An example of such a scheme is as follows:

Water Use	Indicated Water Treatment
Aircraft washrack	Clarification by coagulation and sedimentation; Neutralization
Showers and toilets	Filtration and disinfection; Ion exchange softening
Kitchen and laundry, human consumption	Filtration and disinfection; Ion exchange softening; Possibly demineralization
Hospital, Laboratories	Filtration and disinfection; Demineralization

This approach should result in substantial economies in that only those quantities clearly requiring the highest degree of treatment would receive it. This might be only 1-10 percent of the total design flow of 600,000 gpd.

3) All systems must operate in a temperature range of -25° to 125°F. Water treatment systems generally operate best at high temperatures, although warm water is not the most palatable. The efficiency of water treatment falls with decreasing temperature, primarily due to increased water viscosity and lowered rates of chemical reaction. Water, obviously, must not be allowed to freeze in pipes or treatment units. Extremely low temperature conditions demand protection from freezing and, in most cases, heating of the water.

4) The critical size envelope for the C130 aircraft is three each at 8 ft x 8 ft x 12 1/2 ft, and a total cargo weight not to exceed 28,000 lbs.

Many water treatment units tend to be large because they include tanks designed to allow detention of the water for reaction and sedimentation. Detention times and filter rates appear to be fairly uniform among manufacturers. As a result, units of equivalent capacity are equally bulky. Unless all water treatment units are fully integrated with a single large package or tank, treatment units can be shipped separately and readily fit into the envelopes provided. Even this would be necessary only for the large capacity water treatment units. Many manufacturers, if they were aware of the size and weight limitations, could modify their package units to conform to the required limits.

3. MODIFICATION OF CRITERIA

If substantial economies can be achieved by "tailoring" the water treatment to the various uses at the Bare Base installation, the criteria should be modified. This might be done by adopting a treatment scheme such as the following, for example:

1) Coagulation and sedimentation - all raw water might be coagulated, settled, stabilized and prechlorinated at a site close to the raw water source. The total flow of up to 600,000 pgd of coagulated and settled water would be pumped into the distribution system.

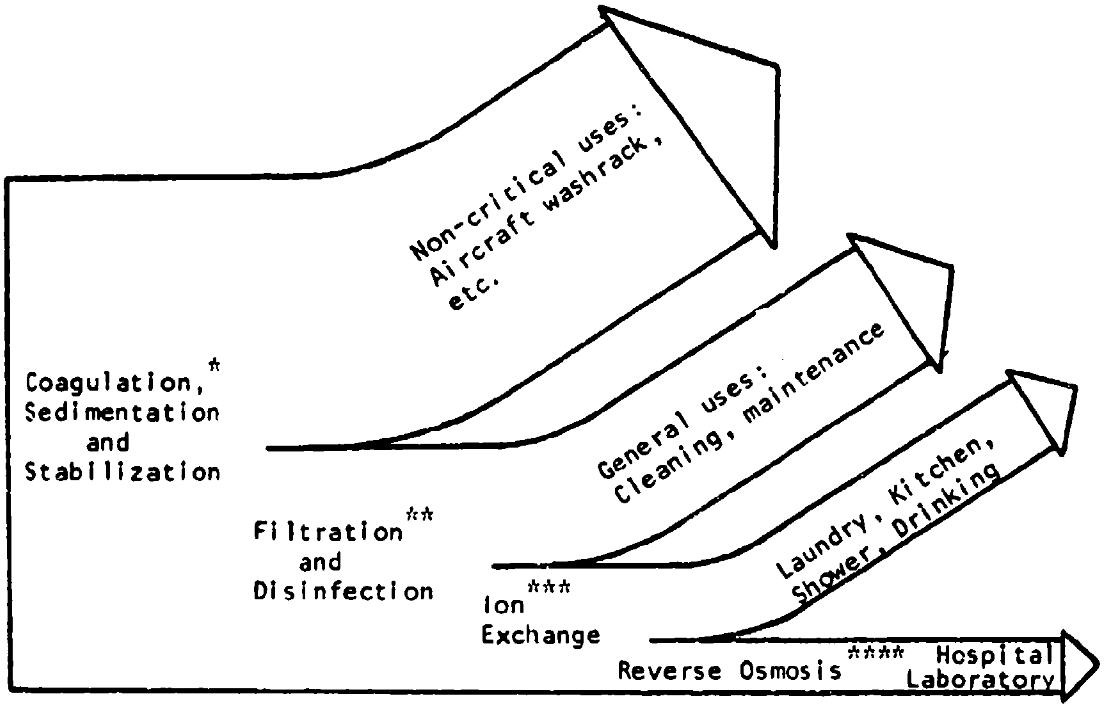
2) In each lateral, a filtration-disinfection unit might be provided. Six units, each rated at 50,000 gpd, could provide up to 300,000 gpd.

3) At shower, kitchen and laundry facilities, ion exchange units could be provided. Four units of 20,000 gpd capacity would yield 80,000 gpd.

4) For critical hospital and laboratory use, reverse osmosis units

could be designed to supply a total of 8,000 gpd of high quality water.

In summary, such a water treatment system might be depicted as follows:



*Most of the solid residue would be produced and retained at this point. Sludge could be applied to lagoons or drying beds and ultimately buried.

**Backwash water could be returned to raw water supply, to lagoons or leaching pits.

***Brine from regeneration could be drained to leaching pits or evaporation ponds.

****Retentate to leaching pit or evaporation ponds.

4. DISPOSAL OF WATER TREATMENT PLANT SLUDGES

None of the manufacturers supplying water treatment plants provided treatment or facilities for the disposal of water treatment plant sludges. The sludges produced in conventional water treatment consist primarily of stable materials, such as iron or aluminum oxides, calcium carbonate, silicates, and a variety of hydroxides. Because of the stability of the sludge and the relatively small quantities produced by package units, disposal is not corsidered to be a major problem. For example, if iron or aluminum are used to coagulate 600,000 gpd of turbid water, roughly 120 to 150 pounds of dry solids might be produced daily. Taking the larger figure, this would amount to a little over two tons per month if the plant operates at full capacity. For quantities such as these, elaborate sludge handling techniques are hard to justify. At the moment, burial, land disposal, or incorporation with wastewater treatment plant sludges destined for incineration seem the most feasible alternatives. Brines may be disposed of using leaching or evaporation pits.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

From the information submitted, there seem to be a substantial number of manufacturers capable of supplying basic and packaged water treatment units. Most of the manufacturers supply units for coagulation and filtration. Many others supply ion exchange and reverse osmosis equipment. While many of the units available could be considered as components of an overall Bare Base water system, no single packaged unit comes even remotely close to meeting all the stringent criteria.

From recent developments in military water supply (Ref. 2) it is clear that the military recognizes that the diversity of military activities require a variety of water treatment devices tailored to the water quality needs of each user. The idea of developing a "black box" which will treat any quality of raw water to the quality required for the most critical military use is indeed attractive. It may even be technically feasible if one is willing to put aside economic considerations. However, the optimum water treatment system for a Bare Base may include a series of treatment modules for (a) coagulation-sedimentation, (b) filtration-disinfection, (c) ion exchange, and (d) reverse osmosis. Once the criteria for each module have been determined, the modules may well be found to be available "off-the-shelf" without major modifications.

This phase of the study of the USAF Air Mobility Program Water Purification System has been devoted to determining what water treatment equipment, having potential Bare Base application, is commercially available. Subsequent work on this project is to be devoted to an analysis of advanced water purification concepts and systems, the selection and

rationale for the recommendation of an optimum system or systems for the Bare Base program, and recommendations for possible future development efforts for promising concepts.

APPENDIX I

Letter from Brigadier General Archie S. Mayes, USAF DCS Civil Engineering, requesting a formal research and development program to achieve pre-engineered, modular, relocatable water supply and waste treatment systems.

To: HQ USAF (AFOCE/AFMSG)

1. The timely provision of adequate utilities systems is the most unresponsive area we have encountered in supporting extended contingency requirements in SEA over the past four years.

2. Our reaction time for vertical facilities has continually been improved by the use of pre-engineered structures and other transportable shelters. A quantum jump in this area has been realized through the development of modular dormitories, officers' quarters, crew quarters, dining halls and hospital facilities. On the other hand, package utilities systems to support such a buildup or for intermediate length deployments have seriously lagged in development. Once initial deployments are supported through the use of Army type field equipment, i.e., field erdalators, burn buckets, etc., no intermediate, quickly erected package systems for water and sewage treatments are available. As a result, conventional brick and mortar plants must be programmed and constructed from "scratch" to satisfy the longer term needs. Meanwhile, the initial field "lashups" are simply expanded by any means possible to support the constant growth that invariably takes place. This has been and is a matter of grave concern to the Medical Service due to high endemicity of enteric disease.

3. The need clearly exists for development of package plants for water and sewage treatment that are similar in concept to the modular/relocatable approach so successfully used for vertical facilities. This approach is already being taken for power generation to eliminate the need for time-consuming and unresponsive construction of stationary base power plants. Such an approach to water and sewage will eliminate the need to build conventional facilities for theater of operation environments, except where it is known that major bases will continue in service for periods of well over five years. Even in this case, the package units will provide timely interim treatment to meet established medical standards during the long lead time associated with conventional design and construction.

4. Our experience in programming, designing and constructing conventional water and sewage systems in SEA has clearly established that, in spite of the best planning, excessive lead times do exist. This is true because of a variety of reasons such as:

a. Design and construction are far more specialized and complex than for most other base facilities.

b. Many of the components for conventional systems are not readily available off the shelf.

c. The ability to "get by" with temporary field lashups often causes these vital utilities to be slipped in favor of items that are readily attainable and seem more closely associated with the mission.

d. Cost escalation tends to eat up funds reserved for utilities as while these are only in the design stage, other facilities are being completed.

5. As a base is developed and expanded over an extended period, new missions with dramatic impacts on base population become a way of life. This coupled with the increasing numbers of Local National employees causes water and sewage treatment to become more and more critical from a public health point of view - both as concerns the protection of the on-base population and the surrounding communities. Basic field sanitation practices at a fixed installation can only be effective for a limited period of time without dangers of the health hazard rising sharply. To forestall this undesirable situation in future deployments, we propose that research and development be initiated on the following:

a. A package water plant that can treat water from a surface source equivalent to that obtained by conventional treatment means. Both prechlorination and postchlorination provisions are essential. With separate detention, this same plant can be expected to adequately treat iron-bearing ground water which is a common requirement. Each package unit should be designed to support a set number of personnel consistent with transportability to the site and erectability on the site. As populations increase, a package unit is simply added to the system when appropriate. Our experience in SEA indicates that a single package to support approximately 2000-3000 personnel is highly desirable. This type of a unit would have put us in business for a considerable period of time at all SEA bases. Even today, two to three package units in this order of magnitude would handle most bases. The package plant should be designed to be aggregated from readily available components or as a pre-engineered package developed by industry. The ability to relocate the equipment should be a consideration, but based on our experience in SEA, not an overriding one. In summary, what we need is a product either prepositioned or available in a timely fashion that can be readily transported overseas, erected with a minimum of specialized know-how and operated by personnel with normal training in career field AFSC 563X0.

b. A package sewage plant that parallels the above is also required. The package sewage plant should be developed to provide approximately 90 per cent reduction of the biochemical oxygen demand in airbase sanitary sewage. Unit capacity should if practical be on the same basis as that provided for water plants. Again, availability, transportability, ease of erection, and simplicity of operation are the key points to be considered in a package sewage treatment unit.

6. Request a formal development program be initiated with industry to achieve a package water and sewage treatment plant capability as outlined above. We believe such a development is a key element to timely, orderly and safe development of bases in the theater of operations.

APPENDIX II

Letter and questionnaire prepared by James A. Mahoney, Project Engineer, Civil Engineering Branch, USAF, requesting information on mobile, packaged water treatment plants.

DEPARTMENT OF THE AIR FORCE
AIR FORCE WEAPONS LABORATORY (AFSC)
KIRTLAND AIR FORCE BASE, NEW MEXICO 87117

REPLY TO: WLDC-TE

SUBJECT: Information Request on Mobile Packaged Water Treatment Plants

TO::

Dear Sir:

This office is interested in obtaining information on mobile (mounted or unmounted) packaged water treatment plants. A survey and report of available equipment based upon the attached "Product Questionnaire" is planned for DOD use. Permission to reproduce the attached "Product Questionnaire" is granted if sufficient forms were not furnished.

The range of capacity of the units of interest are from 2500 to 300,000 gallons per day. It is requested that information be submitted on your units that fall within this range.

This is a request for information only and should not be construed as a request for quotation or an expression of intent or commitment on the part of the government to acquire units. Further, the government is not in a position to in any way provide reimbursement for any information which is submitted in response to this request. An early reply is requested. Information received by 15 April 1969 will be included in the report.

Sincerely,

JAMES A MAHONEY
Project Engineer
Civil Engineering Branch

1 Atch
Product Questionnaire

PRODUCT QUESTIONNAIRE

1. Trade name and/or models designation.

2. Person to contact if additional information is required.

3. Gallon per day capacity.

4. Cost per unit.

5. Weight of plant assembled.

6. Shipping floor area and volume.

7. Dimensions of assembled unit or units.

8. Is plant preassembled?

9. Does manufacturer assemble plant? If customer assembled, do the mechanics require special training?

10. How many man-days required for assembly?

11. Foundation requirements.

12. Power requirements (frequency and wattage - 50/60 or 400 cycles).

13. Modular or add-on capabilities. Can units be placed in series to increase capacity?

14. What treatment process is used?

15. Type chemical used in treatment process or trade name of product. Quantities required per rated output.

Atch 1

MANUFACTURER'S PERFORMANCE DATA

Constituent of Characteristics	Influent mg/l	Effluent mg/l	Standard Test Methods* No	Yes
Physical:				
Color (color units)				
Turbidity				
Microbiological:				
Coliform organisms				
Fecal coliforms				
Inorganic Chemicals:				
Alkalinity				
Ammonia				
Dissolved oxygen				
Flouride				
Hardness				
Iron (filterable)				
Manganese (filterable)				
Nitrate plus nitrites				
pH				
Phosphorus				
Total dissolved solids (filterable residue)				
Removal of metal ions if any				
Organic Chemicals:				
Total organic carbon (TOC)				
Methylene blue active substances				
Oil and grease				
Phenols				
Pesticides removal if any tested				
Radioactivity:				
Any removed if tested for				

* For testing other than Standard Method, use back of questionnaire.

Reference: Standard Methods for the Examination of Water and Wastewater, 12th Edition, 1965

If various tests have not been accomplished, so indicate.

APPENDIX III

A) Companies Which Replied Positively

1. Ajax International Corp.
P.O. Box 4007
Santa Barbara, Calif. 93103

2. Aqua-Chem. Inc.
225 N. Grand Ave.
Waukesha, Wisconsin 53186

3. Aqua Media
1210 Elko Drive
Sunnyvale, Calif. 94086

4. Aqua Nomics, Inc.
11809-J East Slauson Ave.
Santa Fe Springs, Calif. 90670

5. Brennan Chemical Co.
704 No. 1st. St.
St. Louis, Missouri 63102

6. California Filter Co., Inc.
1616 Rollins Road
Burlingame, Calif. 94010

7. The Cosmodyne Corp.
2920 Columbia St.
Torrance, Calif. 90509

8. Crane Company
Dept. TR, 4100 S. Kedzie Ave.
Chicago, Ill. 60632

9. Crane-Glenfied
Box 191
King of Prussia, Pa. 19406

10. Desalination Systems, Inc.
3344 Industrial Court
San Diego, Calif. 92121

11. Dorr-Oliver, Inc.
International Headquarters
Stamford, Connecticut 06904

12. E.I. DuPont De Nemours & Co, Inc.
P.O. Box 525
Wilmington, Delaware 19899

13. Emico Envirotech Co.
770 Welch Road
Palo Alto, Calif. 94304

14. Fuller Company/GATC
P.O. Box 5033
Tuscon, Arizona 85703

15. Foremost Water Systems Co.
15600-03 So. Main St.
Gardena, Calif. 90248

16. Gulf General Atomic, Inc.
P.O. Box 608
San Diego, Calif. 92112

17. Hayward Filter Co.
1673 Placentia Ave.
Costa Mesa, Calif. 92627

18. Har-Van Corp.
6935 W. 62nd St.
Chicago, Ill. 60638

19. Hydromation Filter Co.
Bath, Maine 04530

20. Illinois Water Treatment Co.
840 Cedar St.
Rockford, Illinois 61101

21. Industrial Filter & Pump Mfg. Co.
5900 W. Ogden Ave.
Cicero, Illinois 60650

22. Infilco Co.
124 Bridge St.
Catasavagua, Pa. 18032

23. Ionics, Inc.
65 Grove St.
Watertown, Mass. 02172

24. Kisco Boiler & Engr. Co.
P.O. Box 328
St. Louis, Missouri 63166

A) <u>Companies Which Replied Positively</u> (continued)

24. Kisco Boiler & Engineering Co.
P.O. Box 328
St. Louis, Missouri 63166

25. Millipore Corp.
Bedford, Mass. 01730

26. Neptune Micro Floc., Inc.
P.O. Box 612
Corvallis, Oregon 97330

27. Northwest Filter Co.
528 So. Holden
Seattle, Wash.

28. Osmonics, Inc.
2641 Louisiana Ave., So.
Minneapolis, Minn. 55426

29. The Permutit Co.
E49 Midland Ave.
Paramus, New Jersey 07652

30. Universal Desalting Corp.
1638 Coast Blvd.
P.O. Drawer Q
Del Mar, California 92014

31. Universal Water Corp.
1638 Coast Blvd.
P.O. Drawer Q
Del Mar, California 92014

32. Water Problem Equipment Supply Co.
10448 McVine Ave.
Sunalud, (Los Angeles) Calif. 91040

33. Water Treatment Corp.
12536 Chadron Ave.
Hawthorne, Calif. 90250

34. Western Filter Co.
P.O. Box 16748, Stockyards Sta.
Denver, Colorado 80216

35. Westinghouse Electric Corp.
Heat Transfer Division
Lester Branch
P.O. Box 9175
Philadelphia, Pa. 19113

B) Companies Which Replied Negatively

1. Bath Iron Works Corp.
Bath, Maine 04530

2. Biospherics, Inc.
4928 Wyaconda Rd.
Rockville, Maryland 20853

3. Blaw-Knot Chemical Plants, Inc.
1 Olives Plaza
Pittsburgh, Pa. 15219

4. Can-Tex Ind.
Div. of Harsco Corp.
P.O. Box 340
Mineral Wells, Texas 76067

5. Chemetics, Limited
1837 W. 5th. Ave.
Vancouver 9, British Columbia

6. Ecodyne Corp.
96th & Old Santa Fe Trail
Lenexa, Kansas 66215

7. FMC/Link Belt Div.
Depth TR-68
Prudential Plaza
Chicago, Illinois 60601

8. Graver Water Conditioning Co.
100 U.S. Highway 22
Union, New Jersey 07083

9. Hach Chemical Co.
P.O. Box 907
Ames, Iowa 50010

10. Kenlo Pump Div.
1305 Oberlin Ave.
Lorain, Ohio 44052

11. Koppers Engineered Products
P.O. Box 312
York, Pa. 17405

12. Lakeside Equipment Corp.
222 W. Adams
Chicago, Ill. 60606

13. Marolf, Inc.
1620 N. Hercules Ave.
Clearwater, Florida 33515

14. Ogden Filter Co.
Santa Monica Blvd. & Hoover St.
Los Angeles, Calif. 90029

15. Sanitaire
P.O. Box 744
Milwaukee, Wisconsin 53201

16. Sethco Mfg. Corp.
1 Bennington Ave.
Freeport, New York 11550

17. Suburbia Systems, Inc.
3785 W. 95th.
Leawood, Kansas 66206

18. Topco Co. Div.
Sterling-Salem Corp.
Newgarden Road
Salem, Ohio 44460

19. United States Filter
12442 E. Putnam St.
Whittier, Calif. 90608

20. Walker Process Equipment
Chicago Bridge & Iron Co.
Aurora, Illinois 60507

C) Companies Which Did Not Reply

1. Aer-O-Flo
2. AMF Penfield Div.
3. Aquanox, Inc.
4. Aqua Pure Corp.
5. Autocan Industries, Inc.
6. Barnstead Co.
7. Bayard ML & Co., Inc.
8. Belco Industrial Equip. Co.
9. Beloit-Passavant Corp.
10. BIF, Unit of General Signal Corp.
11. Calgon Corp.
12. Canal Industrial Corp.
13. Chemical Separations Corp.
14. Cherne Industrial Inc.
15. Chicago Heater Co.
16. Clever - Books
17. Cromar Company, Cromarglass Div.
18. Cuno Engineering Corp.
19. Datum Corp.
20. Davco Mfg. Co.
21. Dravo Corp.
22. ELDEB Engineering & Research, Inc.
23. Elgin Softner, Inc.
24. Filcore Water Conditioning
25. Gelber Pumps
26. General Filter Co.
27. General Ionics Corp.
28. Glenfield & Kennedy Inc.
29. Heil Process Equipment Corp.
30. Hydrochem Continental Products of Texas
31. Hydromation Engineering Company
32. Hytek Park
33. Ion Exchange Products, Inc.
34. Jetflo Systems
35. Keene Water Pollution Control Div.
36. Koch Engineering Co., Inc.
37. L-A Water Conditioning
38. Lab-Line Instruments, Inc.
39. Litton Systems Inc., Applied Science Div.
40. Met-Pro Water Treatment Corp.
41. Miracle Water Refiners
42. Penfield Mfg. Co., Inc.
43. Pennwalt
44. Piqua Machine & Mfg. Corp.
45. Polymetrics, Inc.
46. Red Jacket Mfg. Co.
47. Rex Chainbelt, Inc.
48. Richards of Rockford, Inc.
49. Standard UMS Corp.
50. Stearn-Roger
51. Struthers Thermo-Flood Corp.
52. Tailor & Co., Inc.
53. Texsteam Corp.
54. Thermal Research & Engineering Corp.
55. Turbitrol Filtration Systems
56. Ultradynamics Corp.
57. Wallace & Tierman
58. Water Refining Company, Inc.
59. Zurn Industries, Inc.

REFERENCES

1. Mahoney, James A., "Summary of Commercial Waste Water Treatment Plants," TR No. AFWL-TR-69-121, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, September 1969.

2. Mahoney, James A., "Military Environics: Water, Wastewater and Solid Wastes," TR No. AFWL-TR-70-97, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, November 1970.